



*WATER RESOURCES
REPORT 5b*

The Hydrogeology of the IFYGL Forty Mile and Oakville Creeks Study Areas

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PREFACE

Part of the contribution of the Ontario Ministry of the Environment to the International Field Year for the Great Lakes (IFYGL) program is the estimation of ground-water inflow to Lake Ontario from the Canadian side by extrapolating data from selected areas representative of larger hydrologic regions. This report, which describes the hydrogeology of the IFYGL Forty Mile and Oakville creeks study areas, is one in a series of reports dealing with the ground-water regimes of seven, selected, representative areas along the Canadian shore of Lake Ontario.

G. H. Mills, Director
Water Resources Branch

Toronto, January 1979

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ENGLISH - METRIC (SI) FACTORS

<u>to convert</u>	<u>to</u>	<u>multiply by</u>
inches (in)	centimetres (cm)	2.540
feet (ft)	metres (m)	0.305
miles (mi)	kilometres (km)	1.609
square miles (mi ²)	square kilometres (km ²)	2.590
cubic feet/second (cfs)	litres/second (l/s)	28.316
Imperial gallons (Ig)	litres (l)	4.546
Imperial gallons/day (Igp/d)	litres/second (l/s)	5.262×10^{-5}
Imperial gallons/day/ft ² (Igp/d/ft ²)	metres/second (m/s)	5.663×10^{-7}
Imperial gallons/day/ft (Igp/d/ft)	square metres/second (m ² /s)	1.726×10^{-7}
Imperial gallons/min (Igpm)	litres/sec (l/s)	.0758
degrees Fahrenheit (F ⁰)	degrees Celsius (C ⁰) (-32)x .0555	

ABSTRACT

The assessment of the ground-water contribution to Lake Ontario from the hydrogeologic region extending westward from the Humber River around the western end of the lake to the Niagara River was undertaken by the Ontario Ministry of the Environment as part of its contribution to the International Field Year for the Great Lakes (IFYGL) program. The Forty Mile and Oakville creeks study areas are considered to be representative of the ground-water regime in that hydrogeologic region. The hydrogeology of the study areas was assessed utilizing field investigations of the geology, test drilling, data from water-well records on file with the Ministry of the Environment and published literature.

Ground-water supplies are obtained from Upper Ordovician shales which are mantled by a thin veneer of glacial debris. Well productivity is in the specific-capacity range of 0.01 to 1.0 Imperial gallons per minute per foot of draw-down.

An excess of 5.78 and 9.15 inches of precipitation (from April 1, 1972 to March 31, 1973) over the long-term annual average increased the storage of the ground-water reservoir as indicated by the rise of 1.34 and 1.55 feet respectively in the ground-water levels of the Forty Mile and Oakville creeks study areas.

Permeability values, derived from short-term pumping tests, were assigned to the various materials in the study areas. From these values it was estimated that seven cubic feet per second of ground water is discharging directly into Lake Ontario along the shore of the hydrogeologic region.

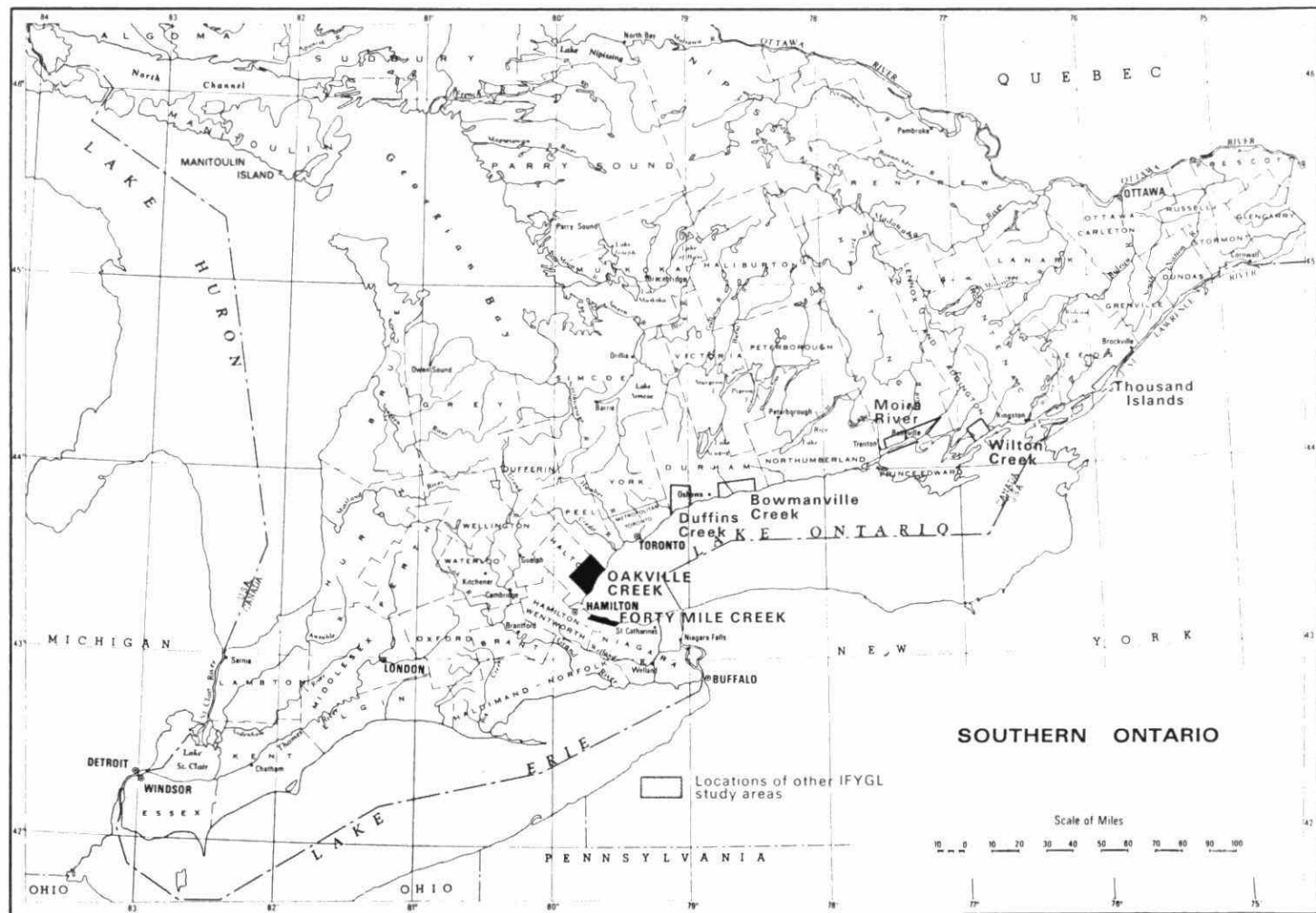


Figure 1. Locations of the IFYGL Forty Mile and Oakville creeks study areas in southern Ontario.

INTRODUCTION

PURPOSE AND SCOPE

Under the sponsorship of the Canadian and United States National Committees for the International Hydrological Decade (IHD) program, the International Field Year for the Great Lakes (IFYGL) program was established to study the various hydrologic aspects of Lake Ontario and its drainage basin. Part of the Ontario Ministry of the Environment's contribution to the IFYGL program was the study of ground-water inflow to Lake Ontario, by extrapolating data from selected areas representative of larger hydrogeologic regions.

The ground-water regime developed in any region is a result of the geology, topography, drainage and climate of that area. The western part of the Lake Ontario basin is a hydrogeologic region where ground-water conditions are considered to be uniform. This region extends westward from the Humber River, near the western limits of the City of Toronto on the north shore of Lake Ontario, around to the Niagara River, across the lake from the City of Toronto. In this region, the Forty Mile and Oakville creeks drainage basins are situated on the south and north shores of the lake, respectively (Figure 1).

For the purposes of the IFYGL study, to determine the amount of ground-water inflow to Lake Ontario, only the area adjacent to the lake was studied. Field investigations were made of the geology and test drilling was conducted to provide information on aquifer characteristics, subsurface geology and ground-water levels in the area. Other aspects of the hydrogeologic assessment utilized information obtained from published literature and water-well records on file with the Ministry.

LOCATION

The Forty Mile Creek study area is located on the south shore of Lake Ontario in part of the Regional Municipality of Niagara and part of the Regional Municipality of Hamilton-Wentworth (Figure 1). This study area is bounded on the north by the south shore of Lake Ontario between longitudes of 79° 32' W. and 79° 44' W., a distance of approximately 10 miles. To the south, the east-west trending Niagara Escarpment, at a distance of one to two miles from the shore, forms the southern boundary of the study area. Forty Mile Creek enters the east part of the study area from the south, at longitude 79° 34' W, and drains

north-northeastward into the lake at approximately longitude $79^{\circ} 33' \text{ W.}$

The Oakville Creek study area is located on the north shore of Lake Ontario, west of the City of Toronto, in the Town of Oakville, Regional Municipality of Halton (Figure 1). This study area is bounded on the south by the north shore of Lake Ontario and on the west and east by the Town Limits of Oakville, a distance of nine miles. The area extends approximately seven miles to the northwest of the Lake Ontario shore. The main branch of Oakville Creek enters the north part of the study area at approximately latitude $43^{\circ} 28' \text{ N.}$ and longitude $79^{\circ} 48' \text{ W.}$ The creek flows eastward through the study area, draining into Lake Ontario at latitude $43^{\circ} 26' \text{ N.}$ and longitude $79^{\circ} 40' \text{ W.}$

ACKNOWLEDGEMENTS

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Appreciation is also expressed to the residents of the area who permitted the use of abandoned wells on their properties as observation wells. Permission to drill additional observation wells on road allowances and right-of-ways, which is herein acknowledged, was granted by officials from the Ontario Ministry of Transportation and Communications, the former townships of Esquesing, Saltfleet, North and South Grimsby, the towns of Oakville and Grimsby, and Lions Valley Park.

The co-operation of the residents of the area during the period of investigation is gratefully acknowledged.

GEOGRAPHY

PHYSIOGRAPHY

Parts of four major physiographic regions, the Peel Plain, the South Slope, the Niagara Escarpment and the Iroquois Plain, as delineated by Chapman & Putnam (1966), are found in the two study areas (Map 1). Only the Iroquois Plain is common to both areas, making up all of the Forty Mile Creek study area but only a small portion of the Oakville Creek study area.

Niagara Escarpment

The Niagara Escarpment is a near-vertical rock face separating two topographic levels in the Niagara Peninsula and has been classified as a physiographic region by Chapman & Putnam (1966). The 350-foot topographic contour follows the base of the escarpment which forms the southern boundary of the Forty Mile Creek study area. The top of the escarpment is approximately defined by the 625-foot topographic contour (Map 1). The escarpment is not present in the Oakville Creek study area.

Iroquois Plain

The Iroquois Plain, as defined by Chapman and Putnam (1966), is the lowland that borders Lake Ontario, which was inundated in late Pleistocene times by glacial Lake Iroquois. A prominent shorebluff from 10 to 20 feet high at about the 375-foot topographic contour level marks the northern boundary of the plain in the Oakville Creek study area (Map 1). The extent of the plain is relatively uniform, with the Lake Iroquois shoreline paralleling the Lake Ontario shore approximately two miles inland from the present lake.

In the Forty Mile Creek study area, the Iroquois shoreline is not a prominent feature and follows along the base of the Niagara Escarpment at an elevation of about 350 feet above sea level (a.s.l.). The Iroquois Plain has an average width of one and one-half miles in the Forty Mile Creek area, extending from less than one mile to over two miles inland from the Lake Ontario shore (Map 1). All of the study area is considered to be part of the Iroquois Plain.

In both study areas, the Iroquois lake bottom consists of a complex of ground moraine and shale bedrock that was modified by wave action in Lake Iroquois. In places a thin veneer of Iroquois beach sand may cover parts of the underlying ground moraine or bedrock. Regional topographic gradients are in the order of 65 feet per mile in both study areas.

South Slope

The South Slope physiographic region forms the bulk of the Oakville Creek study area and is not found on the south side of Lake Ontario. Chapman & Putnam (1966) indicate that the South Slope region in the Oakville area consists of a strip of fluted till plain (ground moraine) adjacent to the Iroquois shoreline and includes the southwest-trending Trafalgar moraine at the north end of the study area. Subdued morainic relief is present in the Trafalgar moraine which has an approximate width of one-quarter mile. This moraine stands in contrast with the till plain to the south and has a maximum relief of approximately 35 feet.

Excluding the narrow strip of the Trafalgar moraine, regional topographic gradients in the South Slope region are in the order of 60 feet per mile or the same as that found in the Iroquois Plain.

Peel Plain

Only a narrow strip of the southern edge of the Peel Plain is present in the Oakville Creek study area (Map 1). According to Chapman & Putnam (1966), this plain is a level to undulating tract of clay soils; form a veneer over the clays the underlying ground moraine, as a result of a temporary lake, ponded between high land to the north and the retreating ice lobe to the south in the Ontario basin. Regional topographic gradients are in the order of 25 feet per mile or roughly half of that found in the bulk of the Oakville Creek study area.

RELIEF

In the Forty Mile Creek study area, maximum relief is in the order of 100 feet; from Lake Ontario on the north, at + 245 feet a.s.l. to the base of the Niagara Escarpment at an elevation of 350 feet a.s.l. in the south.

Maximum relief in the Oakville Creek study area is approximately 400 feet; from Lake Ontario in the south, to the crest of the Trafalgar moraine at an elevation of approximately 640 feet a.s.l. in the north.

DRAINAGE

In the Forty Mile Creek study area, relatively insignificant streams issue from the face of the Niagara Escarpment and drain northward, emptying into Lake Ontario. The only stream not originating in the escarpment is Forty Mile Creek. This creek has cut a V-shaped, narrow gorge through the escarpment and drains a large area on top of the

escarpment equivalent in width to that of the study area below the escarpment (Map 1). Average fall of the streams in the area draining to Lake Ontario is approximately the same as the regional topographic gradient of 65 feet per mile. The flow of many of these streams has been altered by the construction of drainage ditches for agricultural purposes.

Two major streams, Bronte Creek and Oakville Creek, and their tributaries, drain a small part of the Oakville Creek study area. Both the Oakville and Bronte creeks meander in narrow, steep-sided valleys (75 to 100 feet deep), that have been cut into the bedrock. Gradients are in the order of 20 feet per mile along their valley bottoms. Smaller streams, such as Joshua, Morrison and McCraney creeks, drain the intervening areas and empty into Lake Ontario with an average fall of 50 feet per mile, similar to that of the topographic gradient. These smaller streams have their headwaters in the Trafalgar moraine at the north end of the study area, and drain a large portion of the till plain of the South Slope physiographic region.

One major tributary, East Oakville Creek, joins Oakville Creek north of the Trafalgar moraine (Map 1). This tributary drains a region to the north of the study area, flowing south to the Trafalgar moraine which serves as a barrier to further southward flow. The tributary then flows southwestward, parallel to and north of the Trafalgar moraine, to its junction with Oakville Creek. A steep-sided valley that is cut into the bedrock, has been developed for most of the tributary's course.

Major streams emptying into the western end of Lake Ontario are drowned at their mouths as a result of differential uplift. Oakville, Bronte and Forty Mile creeks are notable examples where natural harbours have been created as a result of the increased uplift in the eastern part of the Lake Ontario drainage basin.

CLIMATE

The climate of the study areas is influenced by the presence of Lake Ontario. The Oakville and Forty Mile creeks study areas are in the climatic regions of the "Lake Erie Counties" and the "Niagara Fruit Belt", respectively, as classified by the Ontario Department of Agriculture and Food (1966).

Data from meteorologic stations (Map 1) in each of the study areas are assumed to indicate the climate of the respective areas. The long-term annual precipitation (12-year record) at the Oakville station in the Oakville Creek study area is 31.57 inches and the long-term annual temperature is 45.8°F. A slightly warmer and wetter climate is indicated from the data at the Grimsby station in the Forty Mile Creek study area. Long-term annual records (25-year record) indicate a long-term annual precipitation of 33.90 inches and a long-term annual temperature of 48.5°F. The long-term annual and mean monthly precipitation and temperature values for the above-mentioned stations are shown in Table 1.

TABLE 1. LONG-TERM ANNUAL AND MEAN MONTHLY PRECIPITATION AND TEMPERATURE FROM THE GRIMSBY AND OAKVILLE METEOROLOGIC STATIONS IN THE IFYGL FORTY MILE AND OAKVILLE CREEKS STUDY AREAS (after Environment Canada, 1971)

Station		Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Oakville (12-year record)	Mean Rainfall (inches)	27.25	1.04	0.94	1.45	2.65	2.78	2.61	3.07	3.54	2.71	2.40	2.24	1.82
	*Mean Snowfall (inches)	4.27	1.22	1.03	0.71	0.26	--	--	--	--	--	0.06	0.21	0.78
	Mean Total (inches)	31.57	2.26	1.97	2.16	2.91	2.78	2.61	3.07	3.54	2.71	2.46	2.45	2.60
	Mean Rainfall (inches)	28.79	1.20	1.31	1.90	2.92	2.90	2.91	2.56	3.48	2.98	2.53	2.42	1.68
	*Mean Snowfall (inches)	5.12	1.45	1.23	0.88	0.12	--	--	--	--	--	0.03	0.33	1.08
Grimsby (25-year record)	Mean Total (inches)	33.90	2.65	2.54	2.78	3.04	2.90	2.91	2.56	3.48	2.98	2.56	2.75	2.76
Oakville (12-year record)	Mean Daily Temp. (°F)	45.8	22.8	23.4	31.4	42.9	52.5	62.6	67.7	67.3	61.2	50.4	40.1	27.4
	Mean Daily Max.Temp. (°F)	54.0	29.6	30.8	38.8	51.6	61.9	72.4	77.3	76.7	70.1	59.0	46.7	33.5
	Mean Daily Min.Temp. (°F)	37.4	15.5	15.9	24.0	33.9	42.6	52.5	58.1	57.9	52.2	41.7	33.4	21.3
	Mean Daily Temp. (°F)	48.5	25.2	26.1	33.9	45.4	54.9	66.5	71.8	70.5	63.4	53.2	41.4	29.8
	Mean Daily Max.Temp. (°F)	56.1	31.1	32.4	40.5	53.8	64.4	76.0	80.8	79.2	71.6	60.8	47.2	35.3
Grimsby (25-year record)	Mean Daily Min.Temp. (°F)	40.9	19.1	19.7	27.3	37.0	45.5	56.9	62.8	61.8	55.2	45.6	35.5	24.3

*water equivalent

GEOLOGY

BEDROCK GEOLOGY

General Stratigraphy

Both study areas (Forty Mile and Oakville creeks) are underlain by Paleozoic rocks from the upper part of the Ordovician System. These rocks have been described by earlier workers, notably Sanford (1969), Liberty (1969), Bolton (1957) and Caley (1940). Surface exposures of these rocks are found in the major creek valleys; in the shale plains close to Lake Ontario; in the bluffs along the Lake Ontario shore; and along and near the face of the Niagara Escarpment (Map 2). Table 2, after Liberty (1969), indicates the stratigraphic sequence and includes a brief description of the lithology of the formations present in the study areas.

TABLE 2. BEDROCK STRATIGRAPHY IN THE IFYGL FORTY MILE AND OAKVILLE CREEKS STUDY AREAS (after Liberty, 1969)

ERA	SYSTEM	SERIES	STAGE	GROUP	FORMATION	MEMBER	THICKNESS (feet)	LITHOLOGY	
Paleozoic	Silurian								
	Ordovician	Cincinnatian	Richmondian	Nottawasaga	Queenston		+450	Red Shale	
					Georgian Bay	Upper	30-50	Grey Lime- stone	
						Lower	+500	Inter- bedded Shale and Limestone	
					Whitby	Upper	+170	Blue Shale	
			Middle			+90	Brown Shale		
			Lower			30	Black Shale & Limestone		
			Mays- villian						
						Edenian			

Lithology

Rocks of the Georgian Bay Formation form the bedrock surface in the southeastern part of the Oakville Creek study area. According to Liberty (1969), the lower member of the Georgian Bay Formation is estimated to be greater than 500 feet in thickness and consists of bluish and grey shale that weathers to a buff and yellowish colour. Thin interbeds of hard sandstone, limestone and dolomite, ranging in thickness from a few inches to rarely more than a foot, are present with carbonate beds or hard bands increasing in thickness and number in the upper part of this member. The upper member of the Georgian Bay Formation (Liberty 1969) is 30 to 50 feet thick consisting essentially of grey limestone that varies from calcarenite to crystalline limestone.

Individual bed thicknesses of the Georgian Bay Formation are in the order of several inches to a foot. Shale partings (from one-half inch to three inches in thickness) are commonly found in the upper member. Liberty (1969) suggests that the contact between the upper and lower members be arbitrarily placed where the shale beds of the lower member have thinned to the status of shale partings no larger than two and one-half to three inches in thickness.

The bedrock surface in the remaining portion of the Oakville Creek study area and in all of the Forty Mile Creek study area is comprised of the Queenston Formation. According to Liberty (1969), the Queenston Formation consists of generally unfossiliferous, brick-red, micaceous and arenaceous shales and clay shales with little variation in character. The lowest few feet are often red-mottled green shale and locally contain greenish grey or reddish, ripple-marked limestone and arenaceous and micaceous shales. Caley (1940) indicates that the brick-red shales are seamed by narrow greenish bands along vertical, small joint fissures and also parallel to the bedding planes.

Depositional Environment

According to Liberty (1969), the sediments of the Georgian Bay Formation were deposited in water of moderately shallow depth as indicated by ripple marks, the abundance of fauna and the absence of coarse clastic rocks. Deepening conditions and a facies shift is indicated by the increasing dominance of limestone in the upper member of the Georgian Bay Formation.

Liberty (1969) and Caley (1940) suggest that the Queenston sediments in the study areas originated in the highlands of the Appalachian region and are commonly interpreted as being deltaic estuarine shales in origin. Liberty (1969) suggests that the Queenston shales were deposited as shallow-water sediments, whose iron content was subsequently oxidized during deposition or shortly thereafter. The clastic content, the general unfossiliferous nature and thickness (1100 feet in New York State) of these sediments are interpreted by Liberty (1969) to be indicative of the initiation of rejuvenation of the source area.

Structure

The Paleozoic strata exhibit a gentle regional inclination that varies from 20 to 30 feet per mile to the southwest on the north shore of Lake Ontario (Liberty 1969) and an inclination of 28 feet per mile to the south on the south shore of Lake Ontario (Caley 1940). This disparity in dip direction appears to be a regional feature. The hinge line about which the dip of the strata changes extends well into southwestern Ontario from the western tip of Lake Ontario, in a direction of S69°W. Liberty (1969) indicates that the present attitudes of the Paleozoic strata are essentially those of their initial depositional dip. This suggests that the variation in dip direction is due to structural control at the time of deposition. This structural control was probably provided by the Algonquin Arch, a major geologic feature which extends from the Georgian Bay-Lake Simcoe area through southwestern Ontario between Lakes Huron and Erie, and by the newly-proposed (Liberty 1969) Peterborough Arch which trends southeastward from the Kawartha Lakes, east of Lake Simcoe, to the Bay of Quinte on Lake Ontario.

Bedrock Topography

The elevation of the bedrock surface is illustrated on Map 2. The attitude of this surface was obtained from records of water wells, on file with the Ontario Ministry of the Environment (Map 3), that penetrate the overburden to the bedrock. These data suggest that the bedrock surface is similar to that of the present-day topographic or land surface in both study areas.

In the Forty Mile Creek study area, the bedrock surface rises to the south, away from the Lake Ontario shore (Map 2). In the Oakville Creek study area, the bedrock surface also rises away from the lake, to the northwest. Both bedrock surfaces have an average gradient of approximately 60 feet per mile.

For the most part, present-day drainage appears to be coincident with subsurface drainage initiated previously on the bedrock surface. One buried valley of relatively minor significance was identified in the western part of the Forty Mile Creek study area (Map 2). Data from water-well records indicate that this valley is filled with glacial debris (till) for the most part. In the Oakville Creek area, a buried valley draining to the southeast joins Bronte Creek approximately two miles north of Lake Ontario (Map 2). Karrow (1963) suggests that this buried valley represents an earlier course of Bronte Creek that originated on top of the escarpment (west of the study area) approximately four miles east of the City of Galt. Data from water-well records indicate that near Palermo, the valley is cut more than 100

feet into the Queenston Formation and filled with stratified sands and gravels. These deposits are exposed in the gorge where the valley joins the present-day Bronte Creek (Karrow, 1963). In the eastern part of the Oakville Creek study area, the data suggest that another buried valley lies in the vicinity of present-day Joshua Creek. In the headwaters, the buried valley appears to branch westward under the Trafalgar moraine towards the East Oakville Creek tributary. This buried drainage feature may have been a former channel of the East Oakville Creek prior to draining into Oakville Creek as a result of the drainage-pattern disruption caused by glaciation.

PLEISTOCENE GEOLOGY

The unconsolidated materials overlying the bedrock in the study areas were deposited during the Pleistocene or Glacial Epoch and are considered to be Wisconsinan in age. Investigations of these glacial deposits have been made by earlier workers, notably Coleman (1936), Karrow (1963), Wicklund et al (1963), Presant et al (1965), Chapman and Putnam (1966), Gillespie et al (1971), and Feenstra (1972, 1975).

The deposits are described as being glacial, glacio-fluvial and glaciolacustrine in origin, with thicknesses ranging from a few feet to over 100 feet in the Oakville Creek study area and up to 65 feet in the Forty Mile Creek study area. The extreme thicknesses of glacial materials, as reported above, are associated with the buried valleys discussed in the previous section. In general, a relatively thin veneer of overburden is found capping the bedrock in both study areas. The pre-existing bedrock surface was not likely modified drastically by glaciation (Map 4).

Only the latest events of the last glacial stage (Wisconsinan) of the Pleistocene Epoch are represented by the overburden deposits found in the Forty Mile and Oakville creeks study areas. The surface expression and areal extent of these deposits are shown on Map 4. A more complete sequence of Wisconsinan glacial deposits is found in the Toronto region to the northeast of both study areas (Karrow 1967), indicating that several major glacial advances and subsequent retreats occurred throughout the study areas during Wisconsinan time. It would appear that the Lake Ontario basin was a major pathway used by the glaciers advancing from the east. After filling the Ontario basin, the ice spilled out on to the surrounding high land and merged with ice from lobes advancing from the north to form a vast continental ice sheet over Ontario.

Wentworth Till

The earliest glacial deposits known to occur in both

study areas are believed to be part of the Wentworth Till of Late Wisconsinan age. In its type section, west of the Niagara Escarpment and north of Lake Ontario, this till is sandy, in places stoney, buff to pink-buff in colour, deeply oxidized and irregularly leached of carbonates due to its coarse texture (Karrow 1963). Below the escarpment, to the west of the study area (Cedar Springs re-entrant), Karrow (1963) reported lenses of sandy till (believed to be Wentworth) buried under gravels capped by the youngest Wisconsinan till (Halton Till). Within the Oakville Creek study area, several wells penetrating the buried Bronte Creek valley have reported gravelly till below a thick sequence of sands and gravels that are in turn overlain by the youngest Wisconsinan till. By analogy the gravelly till is assumed to be correlative with the Wentworth Till to the west.

On the south side of Lake Ontario, in the St. Catharines area and along the Welland Canal By-Pass, Feenstra (1972) has identified a lower, coarse-grained, sandy silt till which is considered to be correlative with Karrow's (1963) Wentworth Till on the north side of the lake. To the west, in the Forty Mile Creek study area, several wells penetrating the previously-mentioned bedrock valley, indicate a relatively-thin lower till resting on top of the bedrock. A significant thickness of sand is reported in the well log separating the lower till (Wentworth) from the latest Wisconsin till (Halton) exposed at the land surface.

Halton Till

Glacial till exposed at the land surface in both study areas is considered to represent the last Wisconsinan ice advance out of the Ontario basin. This till, named the Halton Till by Karrow (1963), is a red-brown silt till when oxidized and dark purple when fresh. The colour of the till is due to incorporation of fragments from the Queenston Formation (Karrow, 1963). In the southeastern part of the Oakville Creek area, where the Halton Till overlies the Georgian Bay Formation, the till is grey when fresh and buff coloured when oxidized. Karrow (1963) indicates that the conversion into the typical Halton Till (Queenston facies) can be traced westward from the contact of the Queenston-Georgian Bay formations. The fine-grained nature of the till is indicative of the incorporation of the underlying bedrock which is predominantly shale. The upper part of the till is commonly sub-stratified suggesting deposition in standing water.

The Halton ice advance extended up and over the Niagara Escarpment, terminating in the Waterdown moraines west of Lake Ontario and in the Fort Erie-Niagara Falls-Vinemount moraines south of the lake. These morainic ridges are outside the limits of both study areas. They parallel the escarpment from the Niagara River at the U.S.-Canadian border on the south side of Lake Ontario, swinging around the western end of the lake and extending northward beyond the

Town of Milton. These narrow ridges are not continuous for all of this distance and individual ridges are difficult to correlate (Karrow 1963) from the south to the north side of Lake Ontario. The extent of the ridges has been documented by Chapman & Putnam (1966) with the oldest being the farthest removed from Lake Ontario.

Direction of ice movement is well illustrated on the surface of the Halton Till by numerous flutings that trend westward in the Oakville Creek area and south to southwestward in the Forty Mile Creek area. Sections near the Niagara Escarpment (Feenstra, 1972 and Karrow, 1963) show stratified sediments separating beds of Halton Till. Karrow assumes that these beds represent short oscillations of the ice front, probably corresponding to several of the above-mentioned moraines. Feenstra (1972) suggests that the fluctuating ice margin was possibly grounded as well as floating in glacial lake waters that were ponded around the periphery of the ice sheet.

The Trafalgar moraine, comprised of Halton Till, extends as a low ridge across the extreme north end of the Oakville Creek study area and is correlative with the series of moraines (Waterdown) on top of the escarpment. Karrow (1963) indicates that this moraine was formed during a halt in the retreat of the ice front into the Lake Ontario basin. Flutings and ablation patterns that are common south of the moraine are absent to the north, where shallow sands and varved clay deposits (of Lake Peel) overlie the till (Karrow, 1963), forming the physiographic region of the Peel Plain. Lake Peel, that existed as a glacial lake between the ice front and higher land to north, was drained upon retreat of the ice front from this moraine.

Lake Iroquois Deposits

With the retreat of the ice into the Lake Ontario basin, a high-level glacial lake, Lake Iroquois, was formed between the periphery of the ice front that stood in the St. Lawrence Valley and the surrounding high land. Evidence for an intermediate lake stage prior to the formation of Lake Iroquois is suggested by the difference in drainage-density development in the Oakville area (Map 4) and some shallow-water sand deposits above the Iroquois shoreline near Bronte Creek. Feenstra (1972) postulates that a slightly higher lake stage than Lake Iroquois existed on the other side of Lake Ontario (southern shore) as indicated by deposits of shallow-water sands above the Lake Iroquois shoreline. Further correlation of lake stages will not be attempted herein due to the lack of field data.

The Lake Iroquois shore (Map 4) is an erosional bluff, up to 20 feet high, trending northeastward across the Oakville Creek study area, parallel to the Lake Ontario shore,

at an elevation of 375 to 400 feet a.s.l. In the Forty Mile Creek study area, the base of the Niagara Escarpment is coincident with the Iroquois shore at an elevation of approximately 350 feet a.s.l. Coleman (1936) indicates that the Iroquois shore is tilted upward towards the northeast (N20° E), as a result of differential uplift. The average rise in the shoreline is 2.1 feet per mile to the northeast across the Oakville Creek study area (Wilkinson, 1959).

Relatively thin, shallow-water lacustrine deposits of sand associated with Lake Iroquois are present in both study areas (Map 4). These deposits occur as a veneer covering the Halton Till or Queenston Formation underneath. Karrow (1963) indicates that the distribution of sand appears as a sheet deposit on the Iroquois terrace. Just west of Oakville Creek and in the vicinity of Joshua Creek, small gravel bars associated with the Iroquois shoreline appear to have been constructed during the life of Lake Iroquois.

RECENT DEPOSITS

Alluvial deposits of stratified sand, silt and clay are found along most of the major stream courses in the study areas (Map 4). Lag deposits of gravel are found along the present-day beach of Lake Ontario. These deposits are a result of erosion of the finer materials out of the till forming the bluffs along the present-day shore.

HYDROGEOLOGY

GROUND WATER OCCURRENCE

Moisture infiltrating at the earth's surface moves downward into the subsurface through the "unsaturated zone" into the "saturated zone" and, under the influence of gravity, to a point of natural or artificial discharge in a stream, lake or well. As one aspect of the hydrologic cycle, water stored in the saturated zone is called ground water and natural recharge to this zone occurs either directly from precipitation infiltrating into the ground or from standing bodies of water, including surface streams.

An aquifer is defined as a water-bearing formation that will transmit significant amounts of water to a well. In the exploration for ground-water resources, the connotation of the wording "significant amounts" further defines the term aquifer with respect to the usage of water for domestic, industrial or municipal supplies. An aquifer in the context of this report is one that will at least supply water for limited domestic use. In the study areas, aquifers are found both within the overburden and in the bedrock.

Ground water is stored in the interstices or openings and pore spaces between the grains comprising the material through which the ground water moves. The capacity of any material to absorb, yield or hold water is dependent on the porosity and permeability of the material (i.e. the total number of interstices or voids and the interconnection of these interstices, respectively). Thus, a high porosity material such as shale or clay will not yield large quantities of water due to absorption phenomena resulting from the molecular size and poor interconnection of the pore spaces.

Within the overburden, the most productive materials are the granular deposits of sand and gravel. These deposits do not appear to be abundant in either of the study areas, as indicated from water-well records on file with the Ministry of the Environment. In general, these permeable materials are associated with the buried valleys as delineated on Map 2 and are utilized as a source of ground water. In addition, numerous bored and dug wells penetrating low water-yielding materials such as glacial deposits of till or glaciolacustrine silts and clays are also exploited to supply water for domestic needs. The yield from wells completed in the above-mentioned, low-yield materials, is essentially controlled by the storage capacity of these wells. Studies in the prairies

(Meyboom et al, 1966) suggest that the movement and storage of ground water in glacial tills and some clays is within joints or cracks developed in these materials.

The bedrock comprising both the Queenston and Georgian Bay formations is generally a poor aquifer. Microscopic examination indicates that the bedrock porosity is low **as a result of the** compaction and consolidation of these fine-grained rocks since their deposition. Joints, fractures, cleavage planes and faults have subsequently developed in the bedrock, probably as a result of tectonic processes. Other processes, such as those associated with weathering, have enlarged these planes (including the original bedding planes), creating secondary voids through which the ground water presently flows. These secondary openings tend to become tighter and fewer in number with increasing depth.

GROUND-WATER LEVELS

Change in Storage

The change in storage of the ground-water reservoir can be identified by the measurement of rising and declining water levels in water wells or boreholes. During periods of high precipitation, storage in the ground-water reservoir is increased after the soil moisture deficiency (SMD) in the unsaturated zone is replenished. When the SMD is satisfied, the infiltrating water will percolate downwards into the saturated zone under the influence of gravity. Conversely, storage is decreased under conditions where the infiltrating water is intercepted before reaching the saturated zone, while discharge from the saturated zone continues. These conditions occur during periods of low precipitation and/or excessive use of ground water by man or vegetation.

An observation-well network of private and abandoned wells was established and supplemented with several observation-well installations constructed by the Ministry of the Environment in the Forty Mile and Oakville creeks study areas. The change in water levels was computed for wells in these networks over the Field Year period, from April 1, 1972 to March 31, 1973, and results are presented in Table 3.

TABLE 3. STATIC WATER LEVELS AND CHANGE IN WATER LEVELS (Δs) OF OBSERVATION WELL NETWORKS IN THE IFYGL FORTY MILE AND OAKVILLE CREEKS STUDY AREAS.

Well	Material*	Diameter (inches)	Depth (feet)	Static Level April 1, 1972 (feet)	Static Level March 31, 1973 (feet)	Δs (feet)	Average Δs (feet)
OD-12	OB	60	8	5.48	5.03	+0.45	
OD-1	OB	60	9	4.54	3.99	+0.55	
OD-10	OB	60	10	4.18	3.60	+0.58	
O -10	OB	2	12	10.79	8.91	+1.88	
OD- 8	OB	60	12	5.49	4.56	+0.93	
OD-13	OB	60	12	7.40	5.09	+2.31	
OD-14	OB	60	13	4.70	4.39	+0.31	
OD- 6	OB	60	13	2.10	1.82	+0.28	
OD-15	OB	60	15	7.19	5.65	+1.54	
O - 7	OB	$\frac{1}{2}$	15	3.02	3.93	-0.91	
OD- 7	OB	60	16	11.70	10.00	+1.70	
O - 6	BR	$\frac{1}{2}$	20	11.52	10.52	+1.00	
OD- 3	OB	60	22	18.08	15.78	+2.30	
O -13	BR	$\frac{1}{2}$	28	10.45	10.82	-0.37	
OD-11	OB	60	29	3.90	3.08	+0.82	
O - 9	OB	$\frac{1}{2}$	31	5.99	4.97	+1.02	
O -12	BR	2	33	5.54	5.37	+0.17	
O -14	BR	$\frac{1}{2}$	35	17.89	16.10	+1.79	
O -10	OB	2	37	12.52	7.90	+4.62	
O - 8	OB	$\frac{1}{2}$	39	10.88	9.04	+1.84	
O - 7	OB	2	44	16.73	13.30	+3.43	
O - 6	BR	$\frac{1}{2}$	49	15.35	15.20	+0.15	
OD-16	BR	4	50	8.30	7.30	+1.00	
O -12	BR	$\frac{1}{2}$	68	12.07	10.93	+1.14	
O - 8	OB	$\frac{1}{2}$	69	22.61	16.94	+5.65	
O - 7	OB	2	71	17.12	13.64	+3.48	
O -10	BR	$\frac{1}{2}$	71	17.65	16.55	+1.10	
O - 7	BR	$\frac{1}{2}$	109	17.26	13.78	+3.48	
O - 7	BR	$\frac{1}{2}$	128	17.98	15.10	+2.88	
<u>Oakville Creek Area</u>							<u>+1.55</u>
FM-30	BR	4	17	Flowing	Flowing	0.00	
FM-13	OB	60	20	4.77	4.89	-0.12	
FM-23	OB	60	20	10.10	7.45	+2.65	
FM-28	BR	4	27	12.10	10.54	+1.56	
FM-29	BR	4	29	15.89	13.94	+1.95	
FM-27	BR	5	30	0.55	0.32	+0.23	
FM-26	BR	5	30	2.35	1.57	+0.78	
FM- 1	BR	$\frac{1}{2}$	31	17.21	12.63	+4.58	
FM- 9	BR	5	32	1.92	3.88	-1.96	
FM-20	BR	5	34	19.96	14.65	+5.31	
FM-31	OB	2	35	1.39	1.24	+0.15	
FM- 5	BR	60	35	1.43	1.15	+0.28	
FM-18	BR	4	35	7.39	4.40	+2.99	
FM-24	BR	5	38	15.86	11.30	+4.56	
RR- 2	BR	$\frac{1}{2}$	42	22.05	25.47	-3.42	
FM-32	BR	2	45	2.97	2.80	+0.17	
RR- 1	BR	$\frac{1}{2}$	46	0.02	0.63	-0.61	
FM- 3	BR	8	47	4.66	3.97	+0.69	
JR- 2	BR	$\frac{1}{2}$	50	10.82	9.68	+1.14	
FM- 2	BR	$\frac{1}{2}$	56	15.00	13.84	+1.16	
FM-25	BR	4	57	28.55	19.43	+9.12	
FM- 3	BR	$\frac{1}{2}$	72	4.83	3.97	+0.86	
FM- 2	BR	$\frac{1}{2}$	77	15.08	13.86	+1.22	
FM- 2	BR	$\frac{1}{2}$	105	15.10	13.85	+1.25	
JR- 2	BR	$\frac{1}{2}$	110	10.36	10.48	-0.12	
RR- 1	BR	$\frac{1}{2}$	118	29.39	27.94	+1.45	
RR- 2	BR	$\frac{1}{2}$	121	26.97	25.50	+1.47	
JR- 1	BR	$\frac{1}{2}$	136	23.20	23.06	+0.14	
<u>Forty Mile Creek Area</u>							<u>+1.34</u>

*BR= bedrock and OB= overburden

The data in Table 3 suggest that an overall increase in storage of the ground-water reservoir occurred in both the Oakville and Forty Mile creeks study areas during the Field Year, as indicated by the average rise of 1.55 and 1.34 feet, respectively, of water levels measured in the observation-well networks.

Climatological data, presented in Table 4 below, indicate that excess precipitation over the long-term annual average contributed to the rise in ground-water levels that occurred in both study areas during the Field Year. Unfortunately, the Oakville meteorologic station in the Oakville Creek study area had been discontinued prior to the Field Year and data are not available for that site. Climatological data from the Burlington meteorologic station, approximately seven miles to the southwest of the Oakville meteorologic station, are considered to be representative of the conditions in the Oakville Creek study area. It is assumed, that during the Field Year, an excess of 9.15 inches of precipitation, over the long-term annual average (Table 4), occurred in the Oakville Creek study area as indicated by the data from the Burlington meteorologic station. An excess precipitation of 5.78 inches over the long-term average (Table 4) occurred during the same time interval in the Forty Mile Creek study area as indicated by the data from the Grimsby meteorologic station. The overall average rise of 1.55 feet in the water levels in the Oakville area and a lesser amount of 1.34 feet in the Forty Mile Creek study area reflect these climatological variations during the Field Year.

TABLE 4. AVERAGE ANNUAL PRECIPITATION IN THE IFYGL FORTY MILE AND OAKVILLE CREEKS STUDY AREAS (from Environment Canada, 1971; 1972-1973)

Station	Annual precip. (1/4/72 - 31/3/73)	Average long-term annual precip.	Deviation from long term
Burlington (16 years record)	39.04 inches	29.89 inches	9.15 inches
Oakville (12 years record)	--	31.57 inches	--
Grimsby (25 years record)	39.68 inches	33.90 inches	5.78 inches

Observation Well Hydrographs

Observation-well hydrographs for the years 1970 to 1973 (illustrated in Figure 2) indicate that the maximum fluctuation in ground-water levels over this period of time was approximately 10 feet in the Oakville Creek study area and 21 feet in the Forty Mile Creek study area. Examination of these hydrographs indicates that a general similarity in ground-water fluctuations exists between the study areas. Maximum peaks and lows in the water-level stages occur at the same times. This annual cyclic nature results from the change in the rate of recharge to the ground-water reservoir.

Climatological data for the study areas indicate that the long-term monthly precipitation (Table 1) is relatively constant, ranging from two to three and one-half inches per month. During the growing season (May to October, inclusive) a decline in water levels occurs, reflecting a soil-moisture deficiency (SMD) created in the unsaturated zone from the consumption of available water by vegetation and evaporation from the land surface. A corresponding rise in water levels occurs during the non-growing season (November to April, inclusive) after the SMD in the unsaturated zone is replenished and recharge to the ground-water reservoir resumes.

Minor deviations to this pattern are evident in Figure 2 during the summer of 1972 and winter of 1973 in the Oakville Creek study area. A halt in the decline of water levels occurred during the months of July, August and the first part of September, indicating that recharge to the ground-water reservoir took place at that time, probably as a result of excess precipitation. Data from the Burlington meteorologic station indicate that 3.14 and 5.07 inches of precipitation were recorded for the months of July and August, respectively. These values amount to a cumulative excess of 1.60 inches over the long-term monthly precipitation (Table 1) recorded at the Oakville meteorologic station.

During the months of January and February, 1973, water levels declined in the Oakville Creek study area and then rose to a maximum value in the month of March. The change in precipitation values recorded over the same period of time at the Burlington station appear to be reflected in the fall and rise of water levels in the Oakville Creek study area. A cumulative total of 3.46 inches of precipitation was recorded during the months of January and February at the Burlington station which is 0.77 inches below the long-term monthly normals indicated for the discontinued Oakville station (Table 1). In the month of March, 5.83 inches of precipitation was recorded at the Burlington station which is 3.67 inches above the long-term monthly normal of 2.16 inches at the Oakville station (Table 1).

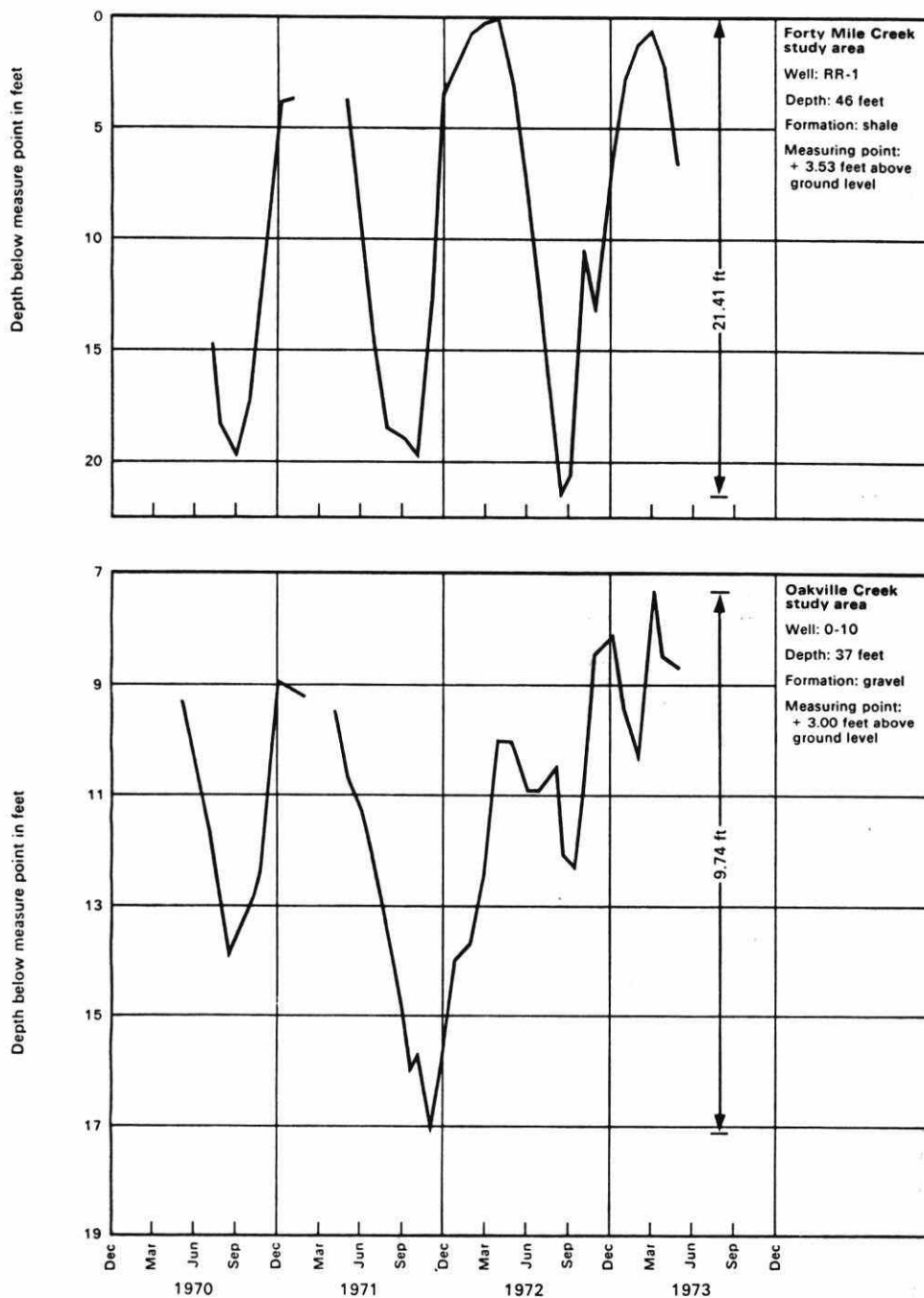


Figure 2. Observation well hydrographs showing maximum fluctuations of water levels in the IFYGL Forty Mile and Oakville creeks study areas.

GROUND WATER MOVEMENT

Ground Water Flow Field

The ground-water flow field is a three dimensional field that occurs from the top of the saturated zone down to a depth where ground-water flow becomes impossible (i.e. where the material in the saturated zone becomes completely impermeable). The ground-water head at any point in this field can be expressed in terms of total head defined by Hubbert (1953) as the sum of pressure head, elevation head and velocity head, at that point; however, the velocity head is so small, for ground-water considerations it can be neglected. The static water level (the level to which water rises) in a well is a measure of the ground-water head or potential.

The total-flow vector (Meyboom et al, 1966) of the three-dimensional, ground-water field can be resolved into two-dimensional horizontal or vertical vectors. The "flow resultant" is the flow component of the ground water in the vertical plane and the "horizontal component" is the flow component of the ground water in the horizontal plane (Meyboom et al, 1966). In either case, the component of flow that is depicted for any given area in this report (flow resultant or horizontal component) is assumed to essentially represent the total flow vector of the ground-water flow field.

Water Level Data

As indicated above, the static water levels in wells are a measure of the potential causing ground-water flow. Water-level data from water-well records, on file with the Ministry of the Environment, suggest that the static water levels of wells completed within different water-bearing horizons are similar regardless of the season or the year in which the wells were drilled. An average value for depth to static water level was computed for 323 bedrock wells in the Oakville Creek study area and 54 bedrock wells in the Forty Mile Creek study area. Values of 14.9 feet (standard deviation of 12.2 feet) and 10.4 feet (standard deviation of 6.9 feet) were obtained for the average, static water levels in the Forty Mile and Oakville creeks study areas, respectively. Although these wells were drilled in different seasons over a span of approximately 20 years and completed in different water-bearing horizons within the bedrock, the average, static water levels are almost the same.

Observation-well data in Figure 2 show the maximum depth to the static water level was fourteen feet below the ground surface (bgs) in December of 1971 (Oakville area) and seventeen feet bgs in September of 1972 (Forty Mile area) for the period 1970 to 1973. The similarity in the data suggest that the general direction of ground-water flow can be determined from these water-level data.

Any anomalously deep water levels can usually be traced to excessive withdrawals or consumption of ground water or to deep wells completed in the less active or stagnant part of the ground-water reservoir.

Potentiometric Surface

The water-level data from water-well records in the study areas were used to compile a potentiometric-surface map for the ground water in the bedrock (Map 5). The ground-water head values (water-level elevations) for the overburden wells are shown separately on the map (Map 5). The similarity in the two sets of data, however, suggest that the overburden and bedrock are also hydraulically connected. For purposes of this report, the overburden and the uppermost part of the bedrock are considered to constitute the active part of the ground-water reservoir.

Lines of equal potential were interpolated between head values of ground water obtained from water-well records on file with the Ministry (Map 5). By definition, ground-water flow is at a direction normal to the lines of equal potential. Examination of Map 5 suggests that the potentiometric surface conforms to the topographic expression of the ground surface and may be considered to be a subdued replica of that surface. The ground-water divides appear to be generally coincident with the surface-water divides and by analogy, areas of recharge and discharge are topographic highs and lows, respectively. Thus, ground-water flow in a lateral direction is controlled by the topography, movement being from topographically high to topographically low areas.

Hydraulic Gradient

Assuming that the "horizontal component" of flow (as illustrated in Map 5) represents the total-flow vector of the ground-water flow field, the slope of the potentiometric surface is the hydraulic gradient (I) under which ground-water movement occurs. Ground-water movement is dependent on the hydraulic gradient (I) according to Darcy's Law, which can be expressed as $Q = KIA$, where:

Q = quantity of flow

K = coefficient of permeability of the porous material

I = hydraulic gradient

A = cross-sectional area through which movement takes place.

The hydraulic gradient (I) is the head loss (in feet of water) per unit distance (foot) of flow path, resulting from the frictional resistance to flow within the voids of the material through which ground water moves.

As indicated earlier, the potentiometric surface (Map 5) is similar to the land surface and ground-water flow is from high to low potential in a direction normal to the lines of equal potential. The hydraulic gradient (I) is in the order of 0.0123 feet per foot (65 feet per mile) for both study areas.

If the "horizontal component" of ground-water flow does not represent the total-flow vector of the ground-water flow field, the slope of the potentiometric surface is then a component of the hydraulic gradient. It could then be assumed that the "flow resultant" (in the vertical plane) represents the total-flow vector of the ground-water flow field. In areas where there is a strong downward or upward component of flow, the vertical gradient, as delineated from observation wells, can approximately represent the hydraulic gradient of the ground-water flow. The vertical gradient is the head loss (in feet of water) per unit distance (foot) of depth.

For the Field Year program, piezometer nests were established at several sites (Map 1) in order to monitor water-level fluctuations and to determine the potential distribution of the ground water in the subsurface. Head measurements (static water levels) obtained from these piezometer installations at depth, were used to compute the vertical gradients at the sites and the results are presented in Table 5.

The average vertical gradient ranges from -0.780 to +0.035 (feet per foot) in the study areas, as illustrated in Table 5. Intermittent upward movement of ground water is indicated in sites 0-7, 0-10, 0-14, JR-2 and RR-2 at various times of the year, suggesting that these sites are in areas of ground-water discharge at that time. At sites 0-10 and 0-7, the upward movement appears to be locally confined to the upper part of the overburden as vertical gradients at depth are in the range of -0.195 to -0.065 (feet per foot), respectively. The observed negative gradients at sites 0-14, JR-2 and RR-2, located at the shore of Lake Ontario, may be local effects largely due to fluctuating water levels in Lake Ontario.

Downward movement of ground water appears to be prevalent at the remaining sites in both study areas, as suggested by the average, negative vertical gradients. These gradients range from -0.042 (site 0-9) to -0.780 (site 0-13) and are larger than the hydraulic gradient of 0.0123, estimated for the "horizontal component" of ground-water flow in Map 5. Therefore the flow resultant is assumed to essentially represent the total flow vector of the ground-water flow field.

With the exceptions of sites 0-7 and 0-8, the vertical gradients tend to increase with depth. If natural ground-water flow is wholly in the vertical direction at these sites,

TABLE 5. COMPUTED VERTICAL HEAD GRADIENTS FROM PIEZOMETER NESTS
IN THE FIVE FOOT MILE AND OAKVILLE CREEKS STUDY AREAS.

Area	Nest	Material*	Depth (feet)	Vertical Gradient (feet per foot)			
				26/5/72	16/10/72	5/1/73	Average
Oakville	0-6	BR	20				
				-0.0920	-0.0700	-0.1820	-0.1147
	0-9	BR	49				
		OB	31	-0.0820	NA**	-0.0015	-0.0417
	0-12	BR	65				
		BR	33	-0.1300	-0.0870	-0.1900	-0.1356
		BR	68	-0.2600	-0.2350	-0.2860	-0.2603
	0-13	BR	106				
		BR	15	-0.0600	NA**	-0.0484	-0.0542
		BR	28	NA**	-0.7600	-0.7900	-0.7600
	0-8	OB	39	-0.3100	-0.4100	-0.3200	-0.3466
		OB	69	-0.2600	-0.1400	-0.2800	-0.2266
Porty Mile	0-10	BR	99				
		OB	12	+0.0016	-0.0019	-0.0016	-0.0006
		OB	37	-0.2050	-0.1600	-0.2200	-0.1950
	0-7	BR	71				
		OB	15	-0.3600	-0.4400	-0.4100	-0.4033
		OB	44	-0.0200	-0.0160	+0.0360	0.0000
		OB	71	-0.0018	-0.0050	-0.0050	-0.0039
		BR	109	-0.0530	-0.0440	-0.0980	-0.0650
	0-14	BR	128				
		BR	21	+0.0250	-0.1060	-0.0280	-0.0353
		BR	35				
	0-2	BR	41	+0.0036	+0.0057	-0.0162	-0.0023
Porty Mile	0-2	BR	110				
		BR	42	-0.0735	+0.1260	+0.0376	+0.0300
	0-1	BR	46	NA**	-0.0982	NA**	-0.0982
		BR	136				
	0-1	BR	46	NA**	NA**	-0.3020	-0.3020
		BR	118				

* OB = Overburden, BR = Bedrock

**NA = Data not available

the observed change in vertical gradients must reflect differences in permeability of the materials at depth (i.e. the product of gradient and permeability from the Darcy Law, $Q = KIA$, must remain constant for a given quantity of flow). This suggests that the permeability of the materials decreases at depth in sites 0-12, 0-13 and 0-10. An increase in vertical gradient is evident in the deepest piezometers at site 0-7 (Table 5). The small vertical gradients in the overburden above the bedrock suggest that ground-water flow is essentially horizontal at this depth. At site 0-8, the average vertical gradient within the overburden has the same order of magnitude (-0.347) as the gradient between the overburden and the bedrock (-0.227). This suggests that the permeability of the overburden overlying the bedrock is essentially the same as that of the bedrock (i.e. assuming natural ground-water flow is wholly vertical).

Flow Pattern

Diagrams showing the vertical distribution of fluid potential (figures 3, 4 and 5) were prepared for both study areas. The flow lines (i.e. "flow resultant") indicated are assumed to essentially represent the total-flow vector of the ground-water field. The lines of section were chosen to parallel the approximate direction of any horizontal flow (Map 5). The flow patterns depicted are in vertically exaggerated cross-sections and the flow lines were constructed according to Van Everdingen (1963).

The section A-A', across the Trafalgar moraine at the north end of the Oakville Creek study area (Figure 3), indicates that the ground-water divide is approximately the same as the surface-water divide. Sections B-B', C-C' and D-D' (figures 3, 4, 5) extend a short distance inland from the Lake Ontario shore. These sections indicate that ground-water flow is to the lake and the shore is in an area of ground-water discharge in both study areas.

AQUIFER CHARACTERISTICS

The water-yielding properties of an aquifer are a function of pore size and their interconnection. For quantitative ground-water studies, an estimate of the aquifer characteristics is required. The most common method for determining the water-yielding properties of an aquifer is by means of a pumping test. The yield of a well, as determined from a pumping test, may be used to provide information on the water-yielding properties of the materials encountered. In addition, pumping test data may also be used to provide an estimate of the coefficients of transmissibility and permeability (commonly referred to as transmissibility and permeability, respectively) of the material in which the well is completed. The coefficient of transmissibility (T) is defined as the rate of flow of water in Imperial gallons per day (Igcd) through a vertical strip of

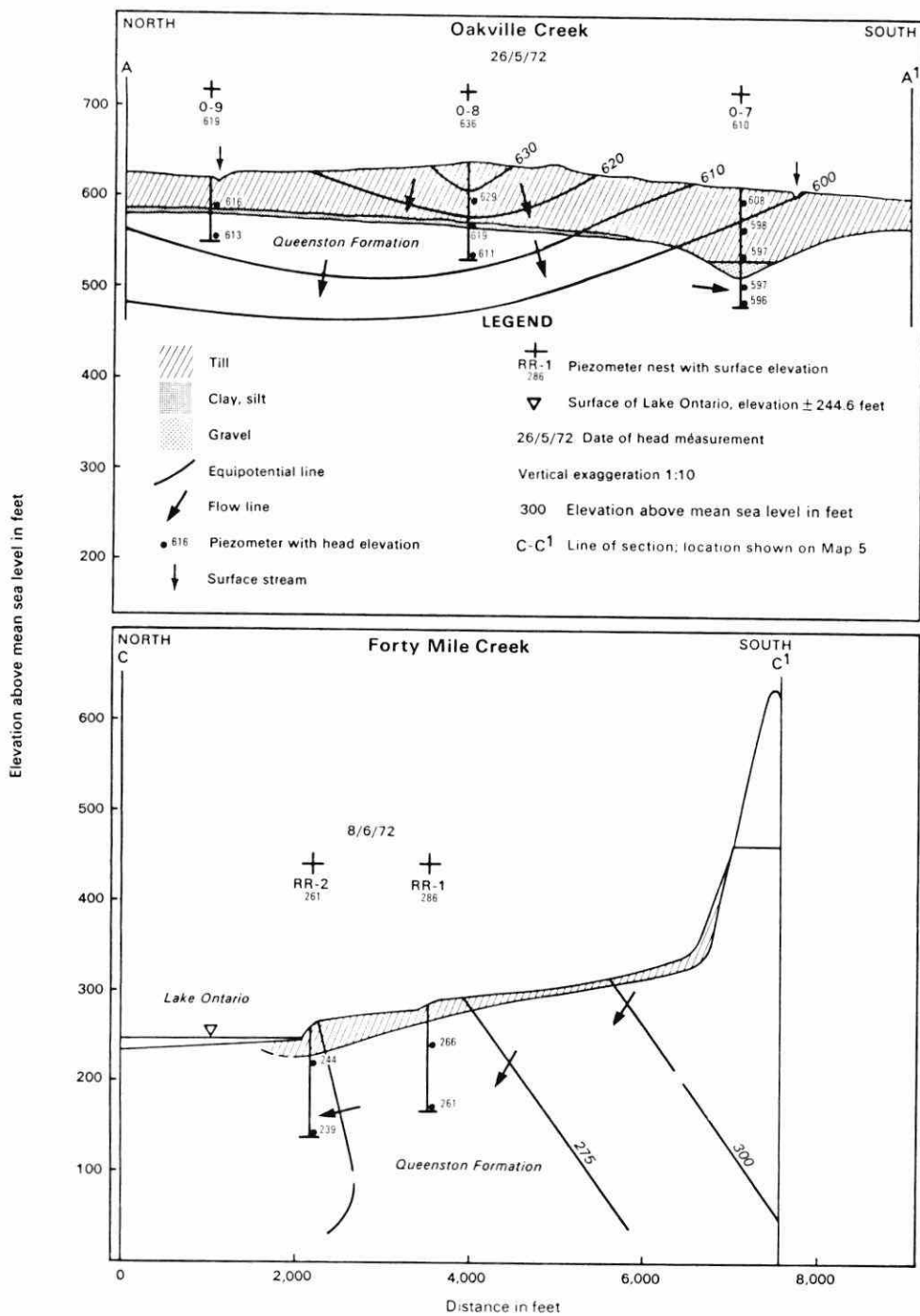


Figure 3. Schematic cross sections showing ground water movement in the IFYGL Forty Mile and Oakville creeks study areas.

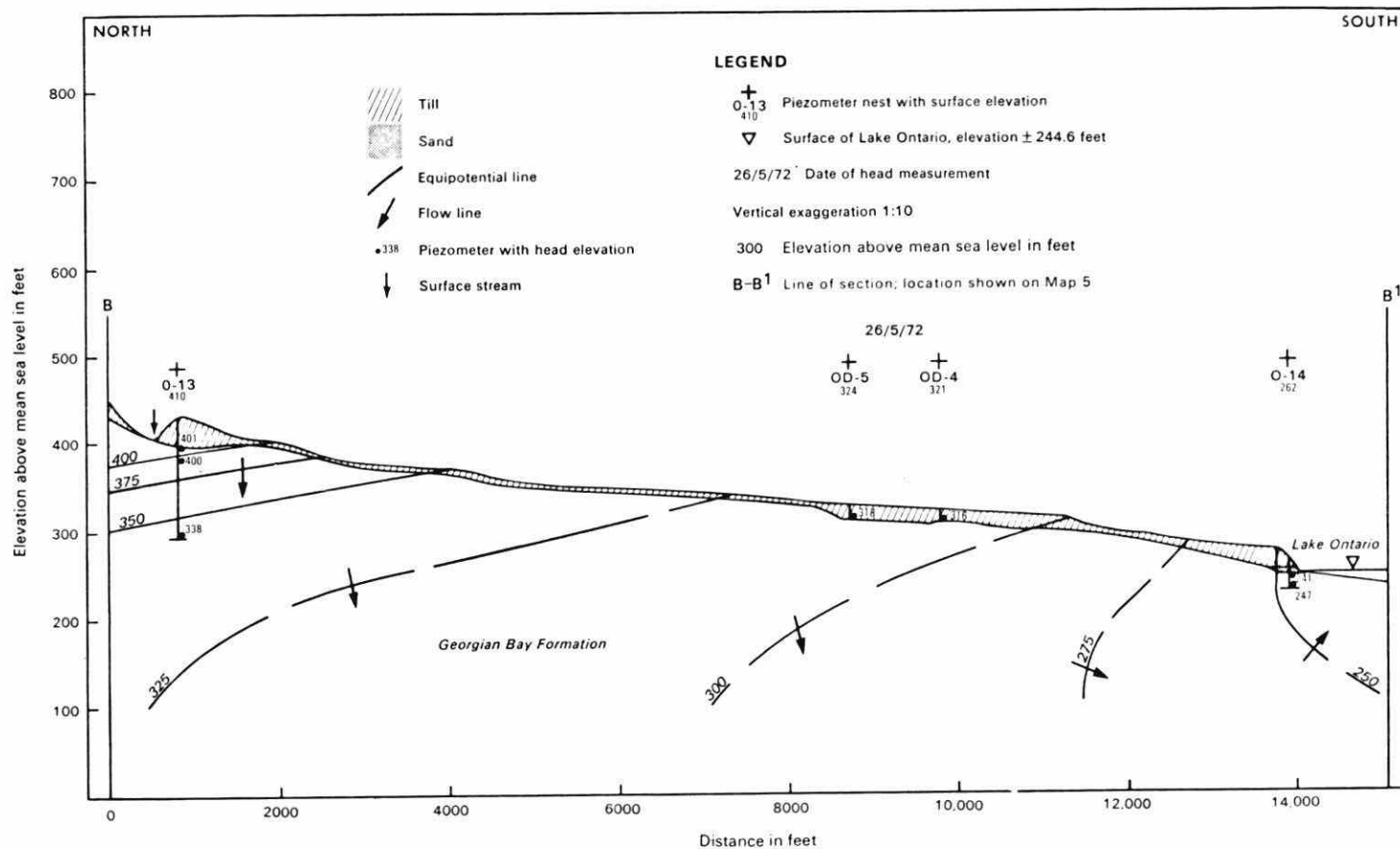


Figure 4. Schematic cross section showing ground water movement in the IFYGL Oakville Creek study area.

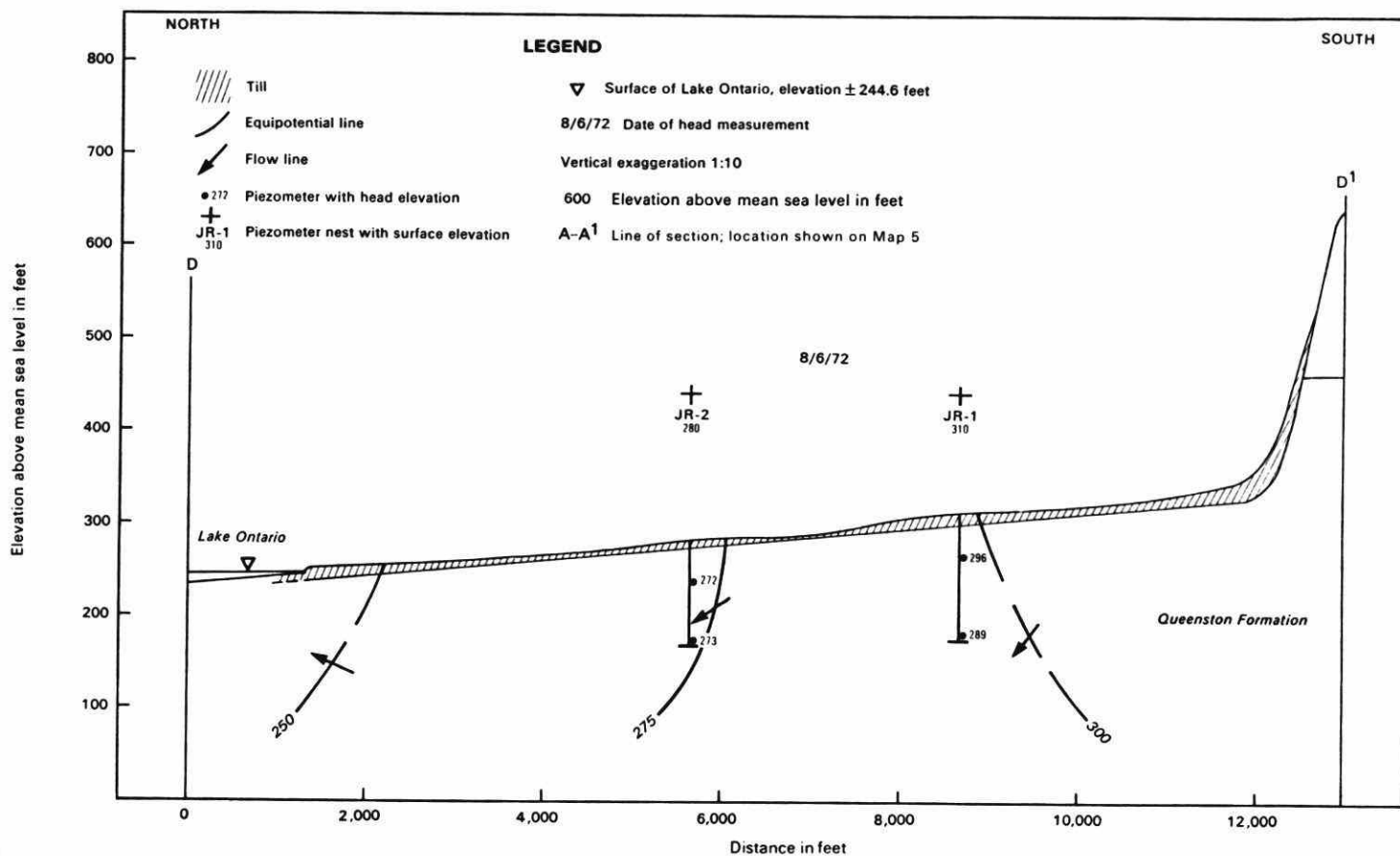


Figure 5. Schematic cross section showing ground water movement in the IFYGL Forty Mile Creek study area.

the aquifer one foot in width and extending the full saturated thickness of the aquifer, under a hydraulic gradient of one foot per foot, at the prevailing temperature of water. The coefficient of permeability (K) may be determined using the relation $K = \frac{T}{m}$ where:

K = hydraulic conductivity
(coefficient of permeability)

T = coefficient of transmissibility

m = contributing thickness of the aquifer

For this study, an estimate of the permeability and transmissibility of the materials through which the ground water flows was required in order to evaluate the quantity of ground water discharging to Lake Ontario.

Well Yields

Statistical analyses of specific-capacity data (derived from pumping tests) by means of specific-capacity frequency graphs (Figure 6) provide a convenient method of comparing the water-yielding properties of the materials in the study areas. The specific capacity of a well is its yield, in Imperial gallons per minute, per foot of drawdown (Igpm/ft), for a stated pumping period and rate. The specific capacity is numerically expressed as Q/s , where:

Q = pumping rate (Igpm)

s = drawdown in feet

Insufficient data were available to compile frequency graphs on the overburden materials. The specific-capacity data for wells completed in the bedrock were tabulated in order of magnitude and the frequencies were computed by the Kimball (1946) method. Values of specific capacity were plotted against percent of wells, on logarithmic-probability paper. The slope of the line passing through the data points indicates the variability of the water-yielding properties of the material; steeper slopes signify greater variability than flatter slopes. Comparison of the frequency curves for the two study areas (Figure 6) indicate a similarity in slope (i.e. variability), with bedrock wells in the Forty Mile Creek area being more productive than bedrock wells in the Oakville Creek area. For example, 50 per cent of the wells completed in the Forty Mile Creek area have a specific capacity of 0.2 Igpm/ft. or more, whereas 50 per cent of the bedrock wells in the Oakville Creek area have a specific

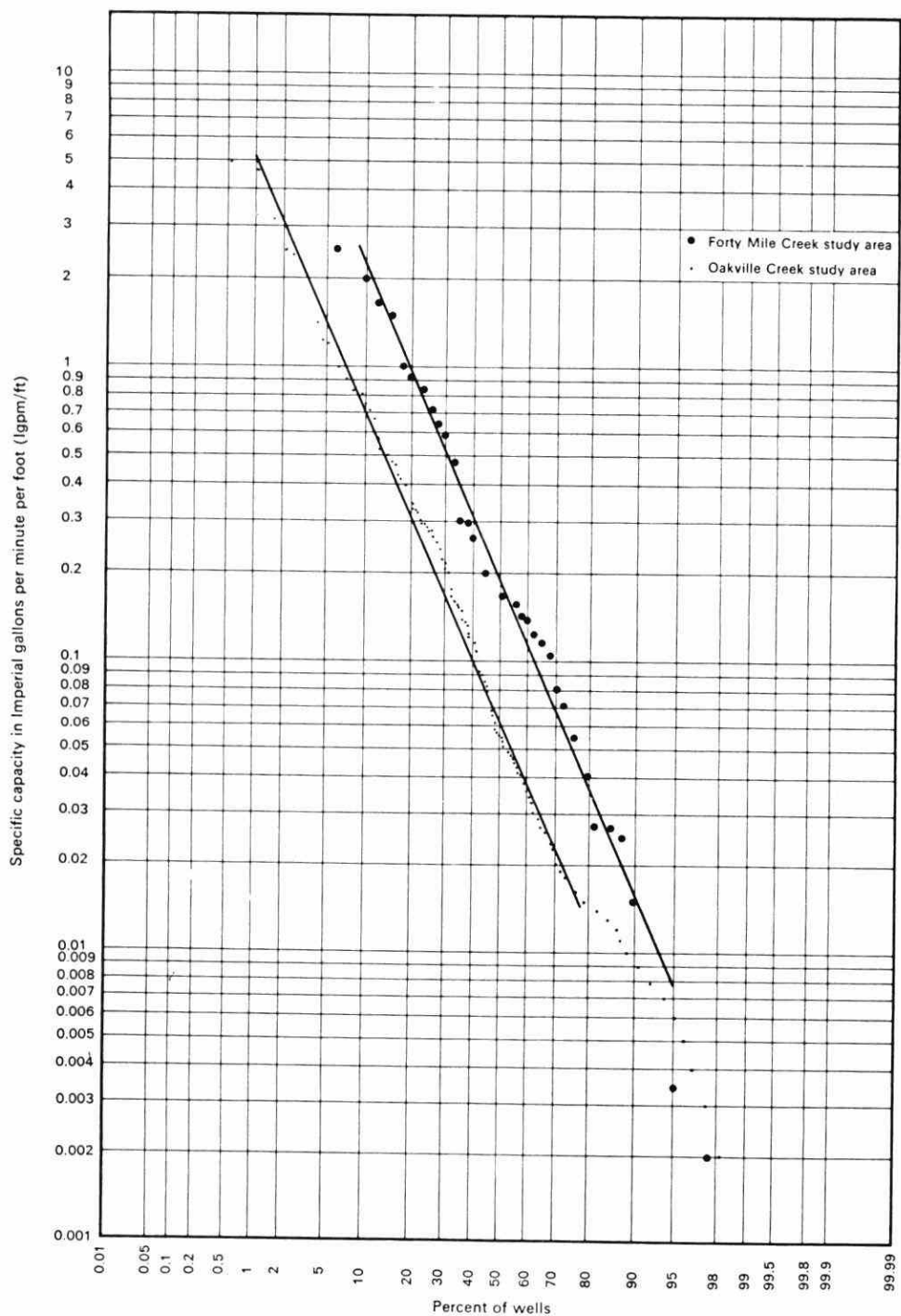


Figure 6. Specific capacity frequency graphs for bedrock wells in the IFYGL Forty Mile and Oakville creeks study areas.

capacity of 0.06 Igpm/ft. or more. The well productivity in the Oakville and Forty Mile creeks study areas is assumed to be related to the density of fractures and joints in the bedrock, as indicated in the earlier section on ground-water occurrence. The above-mentioned data suggest that the fracture density is higher in the Forty Mile Creek area, although this has not been substantiated in the field.

Transmissibility (Modified Non-Equilibrium Well Formula)

Information from water-well records on file with the Ministry of the Environment were utilized to estimate the transmissibility (and by analogy, the permeability) of the different materials from short-term pumping tests of wells in the study areas. Transmissibilities were obtained using the modified non-equilibrium well formula, (Cooper & Jacob, 1964):

$$T = \frac{264 Q}{s}$$

where: T = coefficient of transmissibility (Igpd/ft)

Q = pumping rate in Imperial gallons per minute (Igpm)

s = change in drawdown per $\log_{10}$ cycle (feet).

The derivation of the formula is based on the following assumptions (Johnson, 1966):

- 1) The water-bearing formation is uniform in character and permeability in both horizontal and vertical directions.
- 2) The formation has uniform thickness.
- 3) The formation has infinite areal extent.
- 4) The formation receives no recharge from any source.
- 5) The pumped well penetrates and receives water from the full thickness of the water-bearing formation.
- 6) The water removed from storage is discharged instantaneously with lowering of the head.

Unfortunately, due to the nature of the data (lack of observation wells, partial penetration of the aquifer by wells and non-uniformity of the aquifer, etc.), the above-mentioned assumptions are not met in totality. It is assumed that the transmissibility values obtained from the well-record data are within an order of magnitude of the absolute values.

The results of the computations of permeabilities (transmissibility ÷ contributing aquifer thickness) for the various materials in the study areas are presented in Table 6.

TABLE 6. PERMEABILITIES OF THE MATERIALS IN THE IFYGL
FORTY MILE AND OAKVILLE CREEKS STUDY AREAS

Material	Area	Number of wells	Mean K (lgpd/ft ²)	Standard Deviation (lgpd/ft ²)	Range of K (lgpd/ft ²)
Gravel	Oakville	5	729	1091	39 - 2640
Sand & Gravel	Oakville	4	259	79	164 - 380
Sand	Oakville	2	18	12	6 - 29
	Forty Mile	2	128	6	122 - 134
Till, Clay, Silt	Oakville	4	12	14	0.40-38
	Forty Mile	1	20	--	--
Shale (Q)*	Oakville	138	4	7	0.01-39
	Forty Mile	36	12	17	0.35-60
Shale (GB)**	Oakville	17	9	9	0.01-28

(Q)* Queenston Formation (GB)** Georgian Bay Formation

Transmissibility (Specific Capacity)

The coefficient of transmissibility of an aquifer can be estimated from the specific capacity of production wells. The theoretical specific capacity of a well may be written as: $Q/s = T$

$$\frac{114.6 W(\mu, r_w/\beta)}{\beta}$$

where: $\mu = \frac{2242 r_w^2 S}{T t}$

$$\frac{r_w}{\beta} = \frac{r_w}{\frac{T}{P' m'}}$$

$W(\mu, \frac{r_w}{\beta})$ = well function for leaky artesian aquifers (Hantush, 1966)

Q = discharge of pumped well (l/gpm)

s = drawdown (feet)

r_w = nominal radius of well (in feet)

T = coefficient of transmissibility (l/gpd/ft.)

S = coefficient of storage

t = pumping period (in minutes)

P' = coefficient of vertical permeability of confining beds (l/gpd/ft²)

m' = saturated thickness of confining bed (feet)

Reliable data are not available on the parameters S and P' in the study areas.

In confined aquifers, the coefficient of storage (S) does not show large variations, generally ranging from 10^{-6} to 10^{-4} (Kruseman et al, 1970). The magnitude of S depends on the elasticity of the aquifer material and the fluid. In the study areas, almost all the well records on file with the Ministry indicate confined conditions (i.e. having a static water level above that where the water was found). According to Meyer (Bentall, 1963), any changes in the coefficient of storage (S) correspond to only small changes in the transmissibility (T) and specific capacity (Q/s); therefore, inaccuracy in estimating S is not a serious

limiting factor.

In addition to being dependent on the hydraulic properties of the aquifer and confining beds, the specific capacity (Q/s) will vary as a result of the following factors:

- 1) r_w (the nominal radius of the well) - Q/s increases with increasing r_w , i.e. directly proportional to $\log r_w^2$.
- 2) t (the pumping period) - Q/s decreases with increasing time, i.e. inversely proportional to $\log t$.
- 3) sw (the well loss) - Q/s decreases with an increase in pumping rate in wells with a high sw .

The relationship between the theoretical specific capacity and the coefficient of transmissibility of an artesian aquifer is shown in Figure 7 (after Csallany et al, 1963). It is assumed that the conditions depicted in Figure 7 are applicable to the Oakville and Forty Mile creeks study areas. Transmissibilities were computed from specific-capacity data, using Figure 7, for artesian wells (confined conditions) in the study areas. Permeability results (transmissibility $\div$ contributing aquifer thickness) are presented in Table 7. According to Walton (1962) and Walton et al (1962), the coefficient of transmissibility that is computed from specific-capacity values does not vary significantly between a pumping period of one to eight hours and a limited range of the nominal radius (r_w) of the well. In order to minimize errors, only wells with r_w a pumping period ranging from one to ten hours and with a well diameter of four to eight inches were used in the computations of transmissibility from specific capacity.

The data in Table 7 indicate that the permeabilities obtained using the specific-capacity data are larger by approximately a factor of three than those permeabilities derived from the modified non-equilibrium well formula. Sufficient data on well losses (sw) and hydraulic properties of the confining beds are not available to delineate the permeability to any greater degree of accuracy.

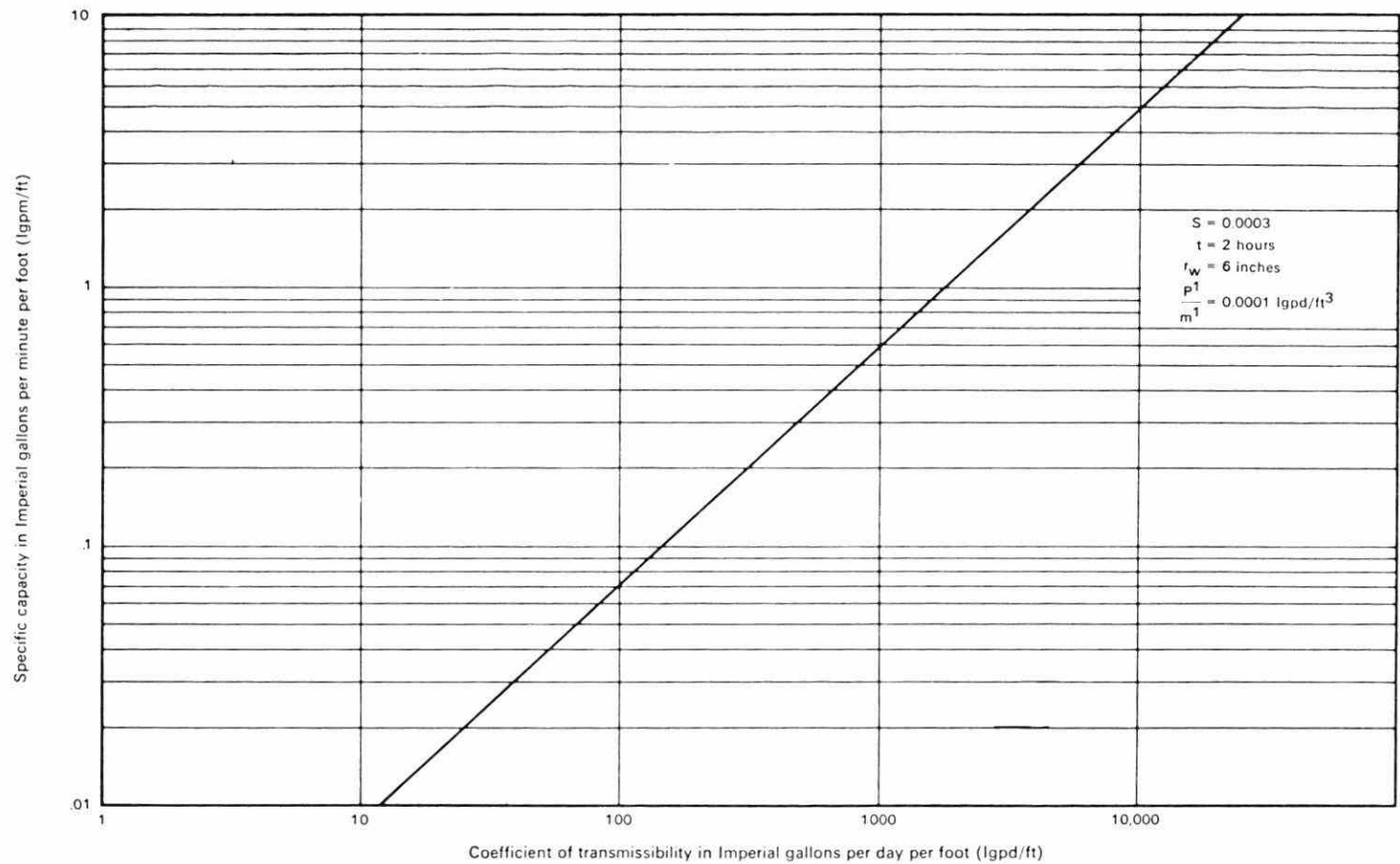


Figure 7. Theoretical relationship between specific capacity and the coefficient of transmissibility (after Csallany and Walton, 1963).

TABLE 7. COMPARISON OF PERMEABILITIES ("K") DERIVED FROM SPECIFIC CAPACITY AND PUMPING TEST DATA OF THE SAME WELLS IN THE IFYGL FORTY MILE AND OAKVILLE CREEKS STUDY AREAS

Material	Area	Number of wells	Mean diameter (inches)	Mean pumping period (hours)	Mean "K" from specific capacity data (l/gpd/ft. ²)	Mean "K" from the modified non-equilibrium well formula (l/gpd/ft. ²)
Gravel	Oakville	4	6.06 (.11)	1.25 (.43)	848 (868)	252 (219)
Sand & gravel	Oakville	3	6.25	1.83 (0.24)	953 (260)	290 (66)
Sand	Forty Mile	2	5.95	1.00	425 (5)	128 (6)
Till	Oakville	1	6.00	4.00	85	38
	Forty Mile	1	6.25	1.00	85	20
Shale (Q)*	Oakville	112	6.14 (0.71)	2.02 (1.48)	13 (35)	4 (8)
	Forty Mile	23	6.31 (0.76)	1.17 (0.57)	57 (80)	14 (21)
Shale (GB)**	Oakville	12	6.35 (1.01)	2.12 (0.95)	35 (40)	10 (10)
(1.18)	Standard deviation					
(Q)*	Queenston Formation					
(GB)**	Georgian Bay Formation					

GROUND WATER CONTRIBUTION TO LAKE ONTARIO

Another form of Darcy's Law, $Q = TIL$, was used to compute the amount of direct ground-water inflow to Lake Ontario, where:

Q = quantity of water in Imperial gallons per day (Igcd)

T = coefficient of transmissibility (Igcd/ft.)

I = hydraulic gradient (feet per foot)

L = width of cross section (feet).

In order that values be assigned for the parameters listed above, several assumptions on the ground-water flow field in the study areas were made. These assumptions with respect to contributing area, depth of active flow, saturated thickness, transmissibility and hydraulic gradient are discussed below.

Contributing Area

As indicated in an earlier section, the area near the Lake Ontario shore is considered to be in a general zone of ground-water discharge. In order to facilitate the computation of ground-water inflow to the lake, it was assumed that the area within a distance of two miles from the shore was representative of the conditions in this zone.

Depth of Active Flow

The mean value of bedrock penetration for 334 wells completed in the bedrock within the Oakville Creek study area was found to be 34 feet. A value of 27 feet for bedrock penetration was indicated for 53 bedrock wells in the Forty Mile Creek area. From the above data it was assumed that the mean value would reflect the practical limit of ground-water exploration for domestic supplies and therefore significant ground-water flow in the bedrock would not extend below 50 feet of bedrock penetration. This arbitrary value of 50 feet of bedrock penetration is considered as the boundary between the active and stagnant parts of the ground-water reservoir.

Saturated Thickness

The static water level reported in the well records was used to determine the saturated thickness of the materials within a distance of two miles from the Lake Ontario shore in both study areas. In some wells (particularly in the Oakville area), a relatively low, static water level in conjunction with a thin overburden thickness indicated that the contribution of ground water from the overburden was negligible.

Transmissibility

Permeability values (table 7) were used to compute the transmissibilities of the materials within the contributing areas of interest. The various materials reported in all the logs of wells within a distance of two miles from the shore were assigned a permeability which was then multiplied by the saturated thickness to determine the overall transmissibility in the active part of the ground-water reservoir. For the few overburden wells in the study areas, an additional transmissibility for 50 feet of bedrock was added to their total. For the computations of the bedrock wells, it was assumed that all the wells penetrated the full thickness (50 feet of bedrock) of the active part of the ground-water reservoir. The total transmissibilities for each well were summed and the results are presented in Table 8. It was assumed that the transmissibility values of about 470 and 970 Igpd/ft. (Table 8) were representative for the areas along the north and south shores of Lake Ontario, respectively, in the hydrogeologic region under consideration.

Hydraulic Gradient

The average hydraulic gradient (I) was assumed to be 0.0123 (Map 5) for the study areas, as indicated in the earlier section on ground-water movement.

Computation of Ground Water Inflow

The values for T and I, as derived above, were substituted in the Darcy formula, $Q = TIL$ to obtain a value of ground-water contribution to Lake Ontario, per mile length of shore line as follows:

Oakville Creek

$$\begin{aligned} Q &= TIL \\ &= 470 \times 0.0123 \times 5280 \\ &= 30,394 \text{ Igpd per mile length} \\ &= 0.057 \text{ cubic feet per second (cfs) per mile length} \end{aligned}$$

Forty Mile Creek

$$\begin{aligned} Q &= TIL \\ &= 970 \times 0.0123 \times 5280 \\ &= 62,866 \text{ Igpd per mile length} \\ &= 0.117 \text{ cubic feet per second (cfs) per mile length} \end{aligned}$$

TABLE 8. MEAN VALUES OF TRANSMISSIBILITY, DEPTH OF STATIC WATER LEVEL, OVERBURDEN THICKNESS AND BEDROCK PENETRATION FOR WELLS COMPLETED WITHIN TWO MILES OF THE LAKE ONTARIO SHORE IN THE IFYGL FORTY MILE AND OAKVILLE CREEKS STUDY AREAS

	Area	Number of wells	Mean overburden thickness (feet)	Mean static water level (feet below surface)	Mean transmissibility (Igcd/ft.)	Mean bedrock penetration (feet)
Wells completed in the overburden	Oakville	3	51 (41)	28 (24)	3075 (4442)	--
	Forty Mile	4	55 (10)	12 (3)	2416 (955)	--
Wells completed in the bedrock (G.B. Formation)	Oakville	26	9 (5)	8 (5)	465 (49)	34 (10)
Wells completed in the bedrock (Q Formation)	Oakville	42	11 (12)	14 (14)	288 (574)	44 (28)
	Forty Mile	55	23 (19)	10 (7)	863 (455)	27 (15)
All wells	Oakville	71			468 (1043)	40 (25)
	Forty Mile	59			968 (628)	27 (15)

(574) Standard deviation

It is assumed that these values of ground-water discharge for the study areas are representative of 32 and 44 miles along the north and south shores, respectively, of Lake Ontario. This region extends westwards from the mouth of the Humber River, near the western limits of the City of Toronto, around the western tip of Lake Ontario and then eastwards along the south shore of Lake Ontario to the Niagara River at the US-Canadian border (Figure 1). From the above, it is estimated that 1.8 and 5.2 cfs of ground water are discharging directly into Lake Ontario from the north and south shores, respectively. These values give a grand total of 7.0 cfs of ground-water discharge to Lake Ontario from the hydrogeologic region for which the Oakville and Forty Mile creeks are considered to be representative. This value is within the range of the values of 14.41 and 5.46 cfs for roughly the same area as computed by Haefeli (1972).

SUMMARY AND CONCLUSIONS

A hydrogeological evaluation of parts of the Oakville and Forty Mile creeks drainage basins was made for the IFYGL program in order to estimate the amount of ground-water inflow to Lake Ontario. The IFYGL Forty Mile and Oakville creeks study areas are considered to be representative of the hydrogeological region extending westward from the mouth of the Humber River, near the western limits of the City of Toronto, around the western tip of Lake Ontario and then eastwards along the south shore of Lake Ontario to the Niagara River at the US-Canadian border (Figure 1). The hydrogeology of the study areas was assessed utilizing field investigations of the geology, test drilling to provide information on aquifer characteristics, subsurface geology and ground-water levels, and information from water-well records on file with the Ministry of the Environment.

The IFYGL Oakville Creek study area lies in parts of three major physiographic regions, the Peel Plain, the South Slope and the Iroquois Plain (Map 1). The Iroquois Plain comprises all of the IFYGL Forty Mile Creek study area (Map 1). Regional topographic gradients are in the order of 65 feet per mile (0.0123 feet/foot) for both study areas.

The climates of both study areas are influenced by the presence of Lake Ontario and as a result are very similar. Long-term, annual meteorologic data indicate that the climate of the Forty Mile Creek study area is slightly warmer and wetter than that of the Oakville Creek study area (Table 1).

The bedrock of the study areas is comprised of Upper Ordovician shales of the Queenston and Georgian Bay formations and is overlain by Wisconsinan drift of the Pleistocene Epoch. Subsurface information from water-well records on file with the Ministry of the Environment indicate that the configuration of the bedrock surface is similar to that of the land surface. With the exception of three buried valleys in the study areas, the drainage initiated on the bedrock surface appears to be coincident with that of the present-day drainage. The bedrock is the primary source of water for domestic and agricultural uses in the study areas.

An excess of 9.15 inches of precipitation in the Oakville Creek study area and an excess of 5.78 inches of precipitation in the Forty Mile Creek study area during the IFYGL period (April 1, 1972 to March 31, 1973), over the long-term annual average, resulted in an increase in storage of the ground-water reservoir. This is indicated by a rise in ground-water levels of 1.55 and 1.34 feet, respectively, in the study areas (Table 3).

Water-level data from water wells completed in different water-bearing horizons in different seasons and years suggest that the general direction of ground-water flow can be determined from these data. Ground-water divides are generally coincident with surface-water divides indicating that ground-water movement is from topographically high to topographically low areas (Map 5). Piezometric data indicate that the area near the Lake Ontario shore appears to be in a general zone of ground-water discharge.

Well-productivity data suggest that the density of fractures may be substantially higher on the south shore of Lake Ontario than on the north shore. The overall productivity of bedrock wells is in the specific capacity range of 0.01 to 1.0 Igpm per foot of drawdown.

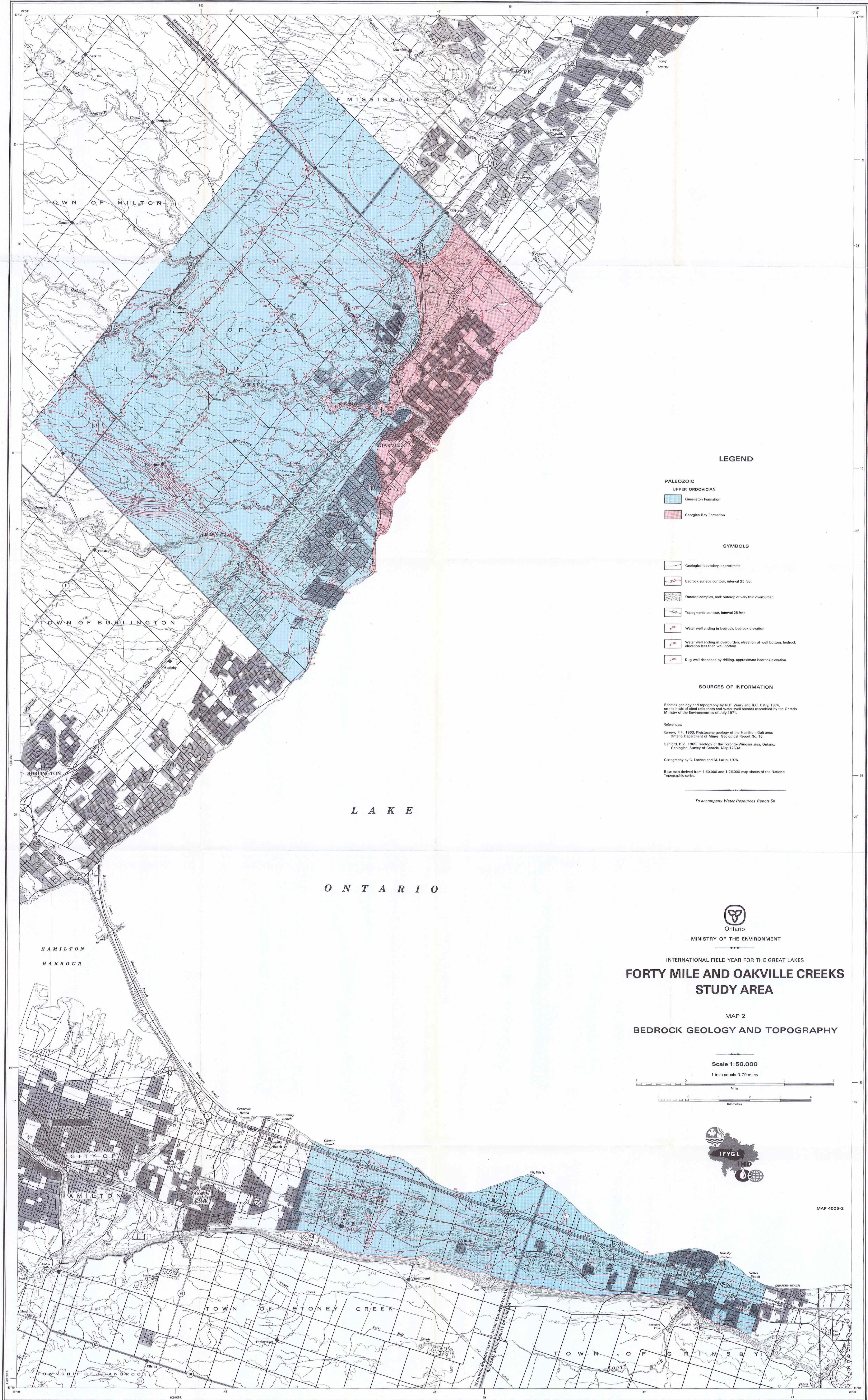
Permeabilities of the overburden materials and bedrock were computed using the modified, non-equilibrium well formula and specific-capacity data. Permeabilities derived from the specific-capacity data are larger by approximately a factor of three than those permeabilities computed from the modified, non-equilibrium well formula (Table 7).

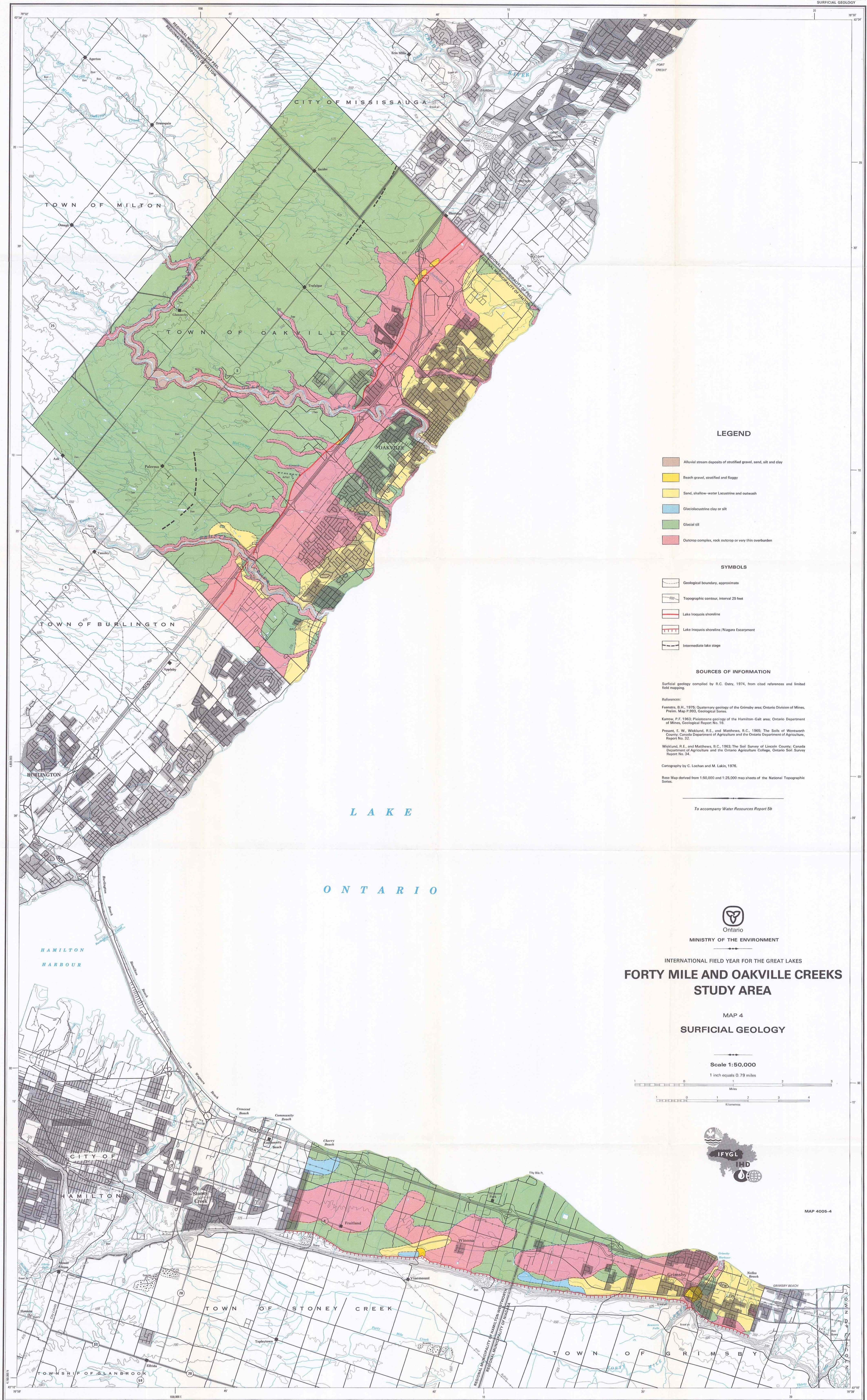
The contributing thickness of bedrock to significant ground-water flow was estimated to be no more than 50 feet. Using permeability values derived from short-term pumping tests, an average transmissibility of 470 and 970 Igpd/foot was computed for materials along the north and south shores of Lake Ontario, respectively. Ground-water inflow to Lake Ontario was estimated to be 0.057 cfs per mile along the north shore and 0.117 cfs per mile along the south shore, giving a grand total of 7.0 cfs for the hydrogeologic region extending from the Humber River around the western end of Lake Ontario to the Niagara River.

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LEGEND

- Alluvial stream deposits of stratified gravel, sand, silt and clay
- Beach gravel, stratified and flaggy
- Sand, shallow-water Lacustrine and outwash
- Glaciolacustrine clay or silt
- Glacial till
- Outcrop complex, rock outcrop or very thin overburden

SYMBOLS

- Geological boundary, approximate
- Topographic contour, interval 25 feet
- Lake Huron shoreline
- Lake Huron shoreline / Niagara Escarpment
- Intermediate lake stage

SOURCES OF INFORMATION

Surficial geology compiled by R.C. Ostry, 1974, from cited references and limited field mapping.

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Cartography by C. Lochan and M. Lakin, 1976.

Base Map derived from 1:50,000 and 1:25,000 map sheets of the National Topographic Series.

To accompany Water Resources Report 5b



MINISTRY OF THE ENVIRONMENT

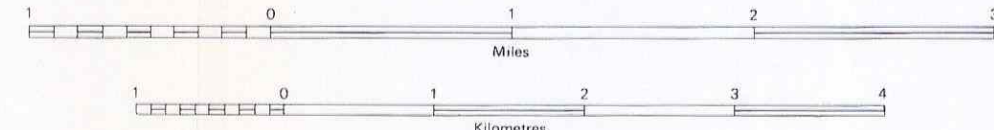
INTERNATIONAL FIELD YEAR FOR THE GREAT LAKES

FORTY MILE AND OAKVILLE CREEKS STUDY AREA

MAP 4 SURFICIAL GEOLOGY

Scale 1:50,000

1 inch equals 0.79 miles



MAP 4005-4



LEGEND

- Water well
- Well number

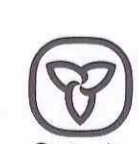
SOURCES OF INFORMATION

Locations of water wells are shown as of July 31, 1971, on the basis of water-well records assembled by the Ontario Ministry of the Environment.

Cartography by C. Lochan, 1976.

Base Map derived from 1:50,000 and 1:25,000 map sheets of the National Topographic Series.

To accompany Water Resources Report 5b



MINISTRY OF THE ENVIRONMENT

INTERNATIONAL FIELD YEAR FOR THE GREAT LAKES

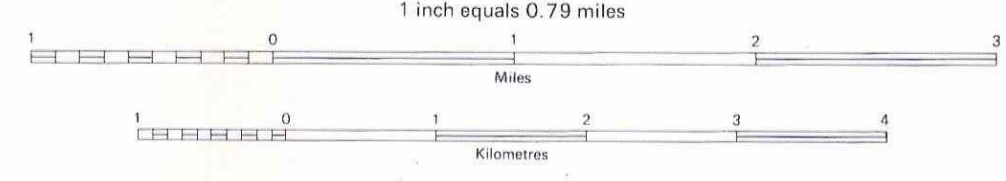
FORTY MILE AND OAKVILLE CREEKS STUDY AREA

MAP 3

LOCATIONS OF WATER WELLS

Scale 1:50,000

1 inch equals 0.79 miles



MAP 4005-3



LEGEND

- Water-level contour, interval 20 feet
- Water well ending in bedrock
- Water well ending in overburden
- Observation well
- Water-level elevation
- Niagara Escarpment
- Line of cross-section

SOURCES OF INFORMATION

Generalized potentiometric surface compiled by N.D. Warty and R.C. Ostry, 1974, from water-well records assembled by the Ontario Ministry of the Environment as of July 1971.

Cartography by C. Lochan and M. Lakin, 1976.

Base map derived from 1:50,000 and 1:25,000 map sheets of the National Topographic series.

To accompany Water Resources Report 5b



MINISTRY OF THE ENVIRONMENT

INTERNATIONAL FIELD YEAR FOR THE GREAT LAKES

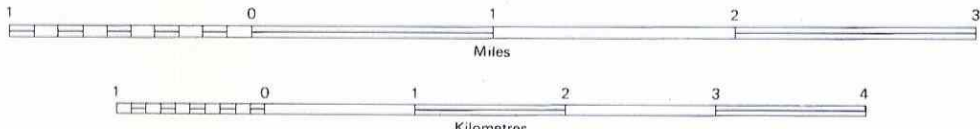
FORTY MILE AND OAKVILLE CREEKS
STUDY AREA

MAP 5

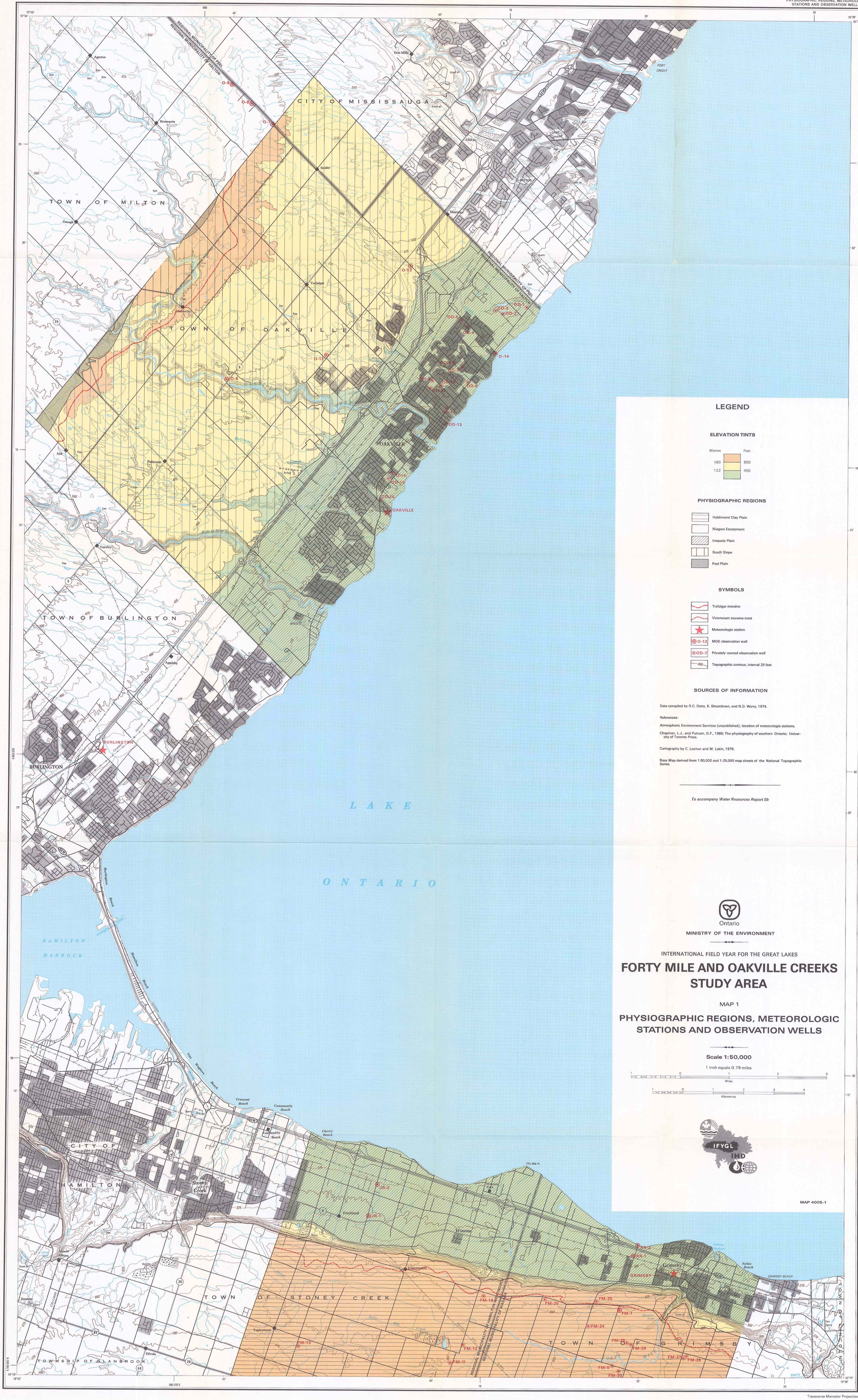
GENERALIZED POTENTIOMETRIC SURFACE

Scale 1:50,000

1 inch equals 0.79 miles



MAP 4005-5



LEGEND

ELEVATION TINTS

Metres	Feet
183	600
122	400

PHYSIOGRAPHIC REGIONS

	Haldimand Clay Plain
	Niagara Escarpment
	Iroquois Plain
	South Slope
	Peel Plain

SYMBOLS

	Trafalgar moraine
	Vinemount moraine crest
	Meteorologic station
	MDE observation well
	Privately-owned observation well
	Topographic contour, interval 25 feet

SOURCES OF INFORMATION

Data compiled by R.C. Ostry, K. Sheardown, and N.D. Werry, 1974.

References:

Atmospheric Environment Services (unpublished), location of meteorologic stations.
Chapman, L.J., and Putnam, D.F., 1966. The physiography of southern Ontario; University of Toronto Press.

Cartography by C. Lochan and M. Lakin, 1976.

Base Map derived from 1:50,000 and 1:25,000 map sheets of the National Topographic Series.

To accompany Water Resources Report 5b



MINISTRY OF THE ENVIRONMENT

INTERNATIONAL FIELD YEAR FOR THE GREAT LAKES

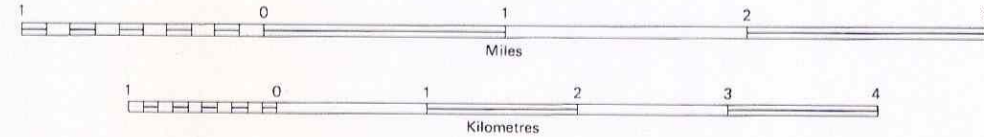
FORTY MILE AND OAKVILLE CREEKS
STUDY AREA

MAP 1

PHYSIOGRAPHIC REGIONS, METEOROLOGIC
STATIONS AND OBSERVATION WELLS

Scale 1:50,000

1 inch equals 0.79 miles



MAP 4006-1



(12057)

MOE/WATER/RES REPT/5b

Date Due

Mar 17/06.			
Oct 22/08			

MOE/WATER/RES REPT/5b

Ostry, R.C.

The hydrogeology of
the IFYGL Forty Mile a00g

(5 maps) c.1 a aa

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